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REPORT

OF THE

NICARAGUA CANAL COMMISSION

REPORT

OF THE

NICARAGUA CANAL COMMISSION

1897-1899

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REAR ADMIRAL JOHN G. WALKER, U. S. N.
PRESIDENT

COLONEL PETER C. HAINS, U. S. A.
Corps of Engineers

PROFESSOR LEWIS M. HAUPT
Civil Engineer

WITH AN ATLAS

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1899

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NICARAGUA CANAL COMMISSION

To continue the surveys and examinations authorized by the Act approved March second, eighteen hundred and ninety-five, entitled "An Act making appropriations for the sundry civil expenses of the Government for the fiscal year ending June thirtieth, eighteen hundred and ninety-six, and for other purposes," into the proper route, the feasibility and cost of construction of the Nicaragua Canal, with the view of making complete plans for the entire work of construction of such canal as therein provided, one hundred and fifty thousand dollars; and to carry out this purpose the President of the United States is authorized to appoint, by and with the advice and consent of the Senate, a commission to consist of one engineer from the Corps of Engineers of the United States Army, one officer of the Navy, who may be taken from the active or retired lists, and one engineer from civil life, said commission to have all the powers and duties conferred upon the commission provided for in said Act.

(Public No. 2. Approved June 4, 1897. Page 54.)

DEPARTMENT OF STATE,
WASHINGTON, August 2, 1897.

Gentlemen:—Pursuant to that portion of the Sundry Civil Appropriation Act (Public No. 2) approved June 4, 1897, constituting a Nicaragua Canal Commission, to be appointed by the President, "to continue the surveys and examinations authorized by the Act approved March 2, 1895, . . . into the proper route, the feasibility and cost of construction of the Nicaragua Canal, with the view of making complete plans for the entire work of construction of such canal as therein provided," you have been appointed by the President members of said Commission, and it is incumbent upon me, as Acting Secretary of State, to communicate to you the following instructions, which have been approved by the President, for the guidance of the Commission:

The Commission is authorized to make such journeys and to do such work as may be necessary to carry into effect the instructions contained in the Act. To facilitate its work, the Commission is authorized to purchase in open market such materials, including instruments, field outfit, supplies, etc., as in its judgment are necessary, and to employ such skilled and other assistance as it may deem essential, and to pay such rates of compensation as may be deemed proper. The approval of the President of the Commission shall be final authority for all expenditures.

An itemized account of all disbursements, with proper vouchers, will be submitted through the Department of State for audit. . . . .

Respectfully yours,
ALVEY A. ADEE,
Acting Secretary.

ADMIRAL JOHN G. WALKER, U. S. N.,
President,
CAPTAIN OBERLIN M. CARTER,
Corps of Engineers, U. S. A.
PROF. LEWIS M. HAUPT,
Civil Engineer.
Members of the Nicaragua Canal Commission.

DEPARTMENT OF STATE,

WASHINGTON, November 3, 1897.

REAR-ADMIRAL JOHN G. WALKER, U. S. N., President; COLONEL PETER C. HAINS, Corps of Engineers, U. S. A.; PROFESSOR LEWIS M. HAUPT, Members of Nicaragua Canal Commission, Army Building, New York City.

Gentlemen:—Referring to the Department's instructions of August 2, 1897, concerning the prosecution of the work of the Nicaragua Canal Commission agreeably to the Act of Congress approved June 4, 1897, I have now to supplement those instructions in the following particulars.

It is impossible to give you specific instructions for the execution of your work beyond referring you to the provisions of the Act referred to and enjoining upon you the desirability and the necessity of prosecuting your labors to completion as rapidly as circumstances will permit. It will be observed, by reference to the Act, that it contemplates a continuance of the previous surveys, "with a view of making complete plans for the entire work of construction of such canal as therein provided."

The Department's understanding of this language is that your report should not only embrace all features of the work authorized by Congress under the present law, but that such field notes or other data as may be acquired and that may be necessary for the complete understanding of the President and Congress, shall be specifically included in your report. In other words, your report should be as full and conclusive upon the subject as it is practicable to make it, to the end that "the proper route, the feasibility and cost of construction of the Nicaragua Canal" may, if possible, be absolutely fixed and determined. . . . .

Respectfully yours,

JOHN SHERMAN.

REPORT OF THE NICARAGUA CANAL COMMISSION.

WASHINGTON, D. C., May 9, 1899.

THE PRESIDENT OF THE UNITED STATES.

Sir:—The Nicaragua Canal Commission, having completed its labors, has the honor to report as follows:

The Commission was organized July 29, 1897, and its first meeting was held on that day. It consisted of Rear-Admiral John G. Walker, U. S. Navy, President; Captain O. M. Carter, U. S. Corps of Engineers; and Professor Lewis M. Haupt, Civil Engineer, members. Captain Carter was relieved from duty with the Commission and was succeeded on October 18 by Colonel Peter C. Hains, U. S. Corps of Engineers.

This Commission has understood the law, approved June 4, 1897, by which it was constituted, to require that all routes heretofore proposed, having any merit, should be considered, new routes that appear to have merit should be developed, and the entire region of canal possibilities should be examined with sufficient thoroughness to enable a just and comprehensive comparison of the various routes to be made and the most desirable one selected. In short, to enable it to make a complete and exhaustive report.

With this in view the Commission established its headquarters in the Army Building in New York and devoted considerable time to a careful examination and study of all data bearing upon the Nicaragua Canal question obtainable in the United States, including Government surveys and surveys by private parties, going back nearly fifty years. During this time an engineering staff was engaged, and the organization of exploring, surveying, geological and hydrographic parties was proceeded with, considerable delay being caused by the necessity for a change of Engineer Members of the Commission. A Commissary Department was also organized for the handling of supplies and food from the United States, as it was impossible to supply the large force employed with promptness and certainty from the resources of Nicaragua in the wild part of the country where the work was prosecuted.

The preliminary studies having been made and the organization completed, the expedition sailed from New York on the U. S. S. "Newport," on December 5, 1897, nearly one hundred strong, and arrived off Greytown December 17. The men and stores were landed as promptly as possible, and as fast as laborers could be engaged, the various parties were put into the field and entered upon the work assigned them.

Through the courtesy of the Secretary of the Navy, the U. S. S. "Newport" was assigned to the service of the Commission for the survey

of Greytown harbor and vicinity, the U. S. S. "Alert" for the survey of Brito and its vicinity, and a strong hydrographic party under Lieut. Hanus, of the Navy, was assigned to the survey of Lake Nicaragua and the San Juan river.

The following instructions for the guidance of the Chief Engineer of the Commission were issued December 21, 1897:

San Juan del Norte, Nicaragua,
December 21, 1897.

Mr. E. S. Wheeler, C. E., Chief Engineer to the Nicaragua Canal Commission.

Sir:—The Nicaragua Canal Commission, appointed by the President under the Act approved June 4, 1897, has selected you to take charge of the field work and direct the operations of the various parties to make the surveys and examinations provided for in the Act above referred to in reference to the Nicaragua Canal.

The scope and character of the work are indicated by the words of the law, "to continue the surveys and examinations . . . into the proper route, the feasibility and cost of construction of the Nicaragua Canal, with the view of making complete plans for the entire work of construction of said canal as therein provided."

Your familiarity with the methods employed in conducting surveys and examinations under the Government with a view to projecting works of improvement renders it unnecessary at this time for the Commission to give you other than general instructions. The details and methods the Commission leaves to you to work out as you find best and as circumstances render advisable, the field parties being directly under your orders. The Commission desires as a final result, to be in possession of all the physical data which bear in any important way upon the construction of the Nicaragua Canal, and it is expected that the accuracy and trustworthiness of these results shall be unquestioned. Due care will be exercised not to unnecessarily duplicate any of the accurate work already done.

Naval hydrographic parties working under the direction of the Commission will survey Brito harbor and vicinity, Greytown harbor and vicinity, Lake Nicaragua and the San Juan river. All these parties will connect their gages with the benches established by your topographical parties, so that their soundings and your work shall conform to the same datum plane. You are expected to confer freely with the chiefs of these parties, that you both may have a clear understanding of your mutual work.

The Commission desires, among other things, that you determine at Greytown and Brito the mean sea levels and connect them, if practicable, with a line of precise levels from ocean to ocean. You will also make such surveys between Brito and Lake Nicaragua as may be necessary to locate the best line for the canal, and such other investigations as may serve to determine the practicability of controlling the lake level by a weir on the west side.

Borings should be made to ascertain the kind and quantity of material to be removed in forming the harbor at each terminus of the canal and along its entire route, including the San Juan river. These borings should be made more numerous at the proposed site of locks, sluices and dams than are necessary elsewhere. Particular attention should be given to the Ochoa and other important dams and to the San Francisco and San Carlos embankment lines. The feasibility of the Canal Company's project hinges on the control of the lake level, the Ochoa dam and the maintenance of the Divide cut. All possible data bearing on these questions should be gathered.

The proper Naval hydrographic party will

make the necessary survey of Lake Nicaragua to determine with sufficient accuracy its area, in order that the question of controlling its level may be properly studied, the extent of the available anchorage between Ometepe island and the west shore be ascertained, as well as the safety of the course which would be followed by steamers between the western entrance to the canal and the head of the San Juan river.

Where the bends of the river are sharp it may be necessary to cut through them. The survey should be made to cover such possible contingency. The disposal of the spoils from the excavations in the river must be taken into consideration. These should be deposited where they will facilitate rather than interfere with navigation.

A suitable number of rain and evaporation stations should be established at the most desirable points in the drainage basin affecting the canal. The records of these should be continued as long as practicable.

The low-level line following the San Juan to near its junction with the Colorado should also be surveyed, and an estimate of its cost determined for comparison with other projects. This line has always been regarded as practicable, and while it has considerably greater length than the comparatively direct line through the Divide, it will avoid some of the difficult engineering problems of the latter route.

The survey of the San Juan should also include the gaging of the river at numerous points, the determination of its slope in high and low stages, its discharge in both stages, the discharge and regimen of the principal streams that empty into it and generally all information necessary to determine the best method of improving its navigation, whether by canalization or otherwise.

All the field parties will receive their instructions directly from you. It is expected, however, that you will keep the Commission fully informed as to the character of the work being done and the methods adopted by you in doing it. For this purpose you will submit monthly reports to the Commission (which shall contain a concise history of the operations and progress of the work), and such special reports as may from time to time be necessary. These instructions are not intended to be final and complete, but may be supplemented by others from time to time as the exigencies of the work demand.

I am, very respectfully,

J. G. WALKER,
President of the Commission.

The Commission remained in Greytown until January 8, 1898, when it proceeded in a special steamer, kindly placed at its disposal by the Nicaraguan Government, to the examination of the San Juan river from the sea to where it leaves Lake Nicaragua, including the Colorado branch.

Five days were occupied in this examination. The Commission, arriving at Fort San Carlos, the head of the San Juan river, on the evening of January 13, proceeded at once by steamer to San Jorge, where it arrived on the following morning, and after putting ashore its equipment, supplies and extra baggage, continued to Granada and Managua for the purpose of paying its respects to the President of the Republic.

Arriving at Managua on the afternoon of the 15th of January the Commission was specially received by the President at 8 o'clock, on the same evening, with all the ceremonies and honors pertaining to such occasions. During its stay in Managua every attention was shown by the President, members of the Cabinet and

other officers of the Government. On the morning of the 18th, the Commission called upon the President to take formal leave and then proceeded by rail to Granada, was transferred to the lake steamer "Victoria," and reached San Jorge late the same afternoon, arriving at Rivas shortly afterwards, where temporary headquarters were established.

Promptly upon its arrival at Rivas the Commission took up the investigation of the canal route from the lake to the Pacific, and remained, either in Rivas or upon the proposed line of the canal, until February 13, having been somewhat delayed by an attempt at a revolution during that period.

On the 13th the Commission left by steamer for San Carlos, at the head of the river San Juan, arriving at that point on the morning of the 14th.

After inspecting the work of the parties under Lieutenant Hanus, U. S. N., and Mr. Stuart, Assistant Engineer, the Commission, on the following morning, proceeded down the river, landing that afternoon at Ochoa, and, after examining the work going on in that neighborhood, which included borings at the proposed site of the Ochoa dam, started on foot upon the trail over the Divide, for a personal examination of that part of the line, arriving at Greytown at 6 P. M. on the 21st.

The Commission remained in Greytown until February 27, when it left on board the U. S. S. "Newport" for Port Limon, Costa Rica, arriving there on the following day, and proceeding by special train, provided by order of the Costa Rican Government, to the capital (San José), for the purpose of paying its respects to the President of Costa Rica. The Commission was pleasantly received by the President, by special appointment, at 8 P. M., March 1. The next day was spent in visiting the neighborhood of the capital, leaving San José by special train on the morning of the 3d for Port Limon, and going immediately on board the "Newport." During the trip to and from San José the cuts and embankments along the line of railroad were carefully observed with a view to obtaining information with regard to the stability of slopes in tropical regions in connection with the proposed canal.

The "Newport" sailed at 6 P. M., March 3, for Colon, arriving the following day (March 4). The five succeeding days were spent in examining the Panama Canal line, the work being done, and the plans, drawings and data in the office of the company in Panama.

In this connection the Commission wishes to express its warmest thanks to Monsieur Belin, the Director-General, and to the officers of his staff, for their kindness and untiring efforts to facilitate its work in every way possible, also to Mr. John F. Shaler, the Superintendent of the Panama Railroad, for his aid, assistance, personal efforts and care during its entire stay upon the Isthmus.

On the 10th, having taken leave of the officials at Colon, the "Newport" sailed for Port Limon and Greytown, arriving at Greytown on March 12.

On March 26 the Commission, having completed its personal examination of the proposed Nicaragua Canal Route, took its departure for the United States, leaving its working parties in the field to prosecute the work assigned them under the direction of Mr. E. S. Wheeler, its Chief Engineer.

Much delay to the work and great annoyance to working parties were caused by attempts at revolution and by the strained relations between the Governments of Nicaragua and Costa Rica,

which rendered it difficult and often impossible to forward supplies, provisions and orders to working parties in the field and to receive reports from them. It is a difficult country in which to carry on work of the kind assigned to this Commission at any time, but the difficulties were increased many fold, and great delay was caused by the disturbed conditions referred to. The outbreak of the war between the United States and Spain was, also, a serious matter. It deprived the Commission of two ships and the naval parties which were working with and under its direction, rendering a new organization of parties necessary and with a much decreased force.

Further delay was caused by the assignment of Colonel Hains to military duty in command of troops at Chickamauga, and later, in Porto Rico.

But in spite of these troubles and delays the work was prosecuted as rapidly as practicable.

As portions of the work were completed, parties were withdrawn, until the last surveying party left Greytown, February 18, 1899, leaving 13 men in the country at 10 stations for the purpose of continuing the observations for rainfall and evaporation, and for the gaging of the lake and the various rivers necessary to a complete understanding of the hydrology of the region of the country through which a canal across Nicaragua must pass.

Soon after the Commission's arrival home, the necessities of the war forced it to vacate its headquarters in the Army Building in New York, and they were removed to Washington, where the work of examining, computing and assembling the data has been steadily prosecuted.

The Commission desires to express its obligations to the Maritime Canal Company, which kindly and freely furnished all data and information in its possession;

To the Navy Department, for assistance with ships, parties and instruments;

To Commanders Tilley and Leutze, commanding the U. S. S. "Newport," and the U. S. S. "Alert," for their excellent surveys of Greytown and Brito;

To the Director of the Geological Survey for the services of C. W. Hayes, Geologist, and A. P. Davis, Hydrographer;

To the Chief of Engineers and to the Superintendent of the Coast Survey for instruments kindly loaned;

To the Panama Canal Company and the Panama Railroad for aid and courtesies rendered;

To E. S. Wheeler, C. E., Chief Engineer to the Commission, and to the members of the engineering staff for their faithful services in connection with the work.

Physics.

To secure the best location for the canal careful attention must be given to the physical features of the isthmus and their adaptation to the purpose.

As the reports of the specialists, hereto annexed, cover the subjects of geology, topography, hydrology and meteorology quite fully, it would seem unnecessary to do more than call attention to a few distinct features which characterize the route on which this Commission is directed to report.

Lake Nicaragua.

It is an interesting and peculiar feature of this route that in early geologic time the lake was evidently an arm or bay of the Pacific ocean, while the Continental Divide traversed the isthmus to the eastward in the vicinity of Castillo Viejo, and the Rio San Juan, as an outlet of the lake, had no existence. This is attested

by the remains of an old river channel of large dimensions which crossed the Western Divide and formed the outlet of the lake after it became separated from the ocean, and by other geologic features.

An old drainage channel is also traceable under the Rio San Juan west of Castillo, which has gradually filled up with alluvium to the present bed of the stream. There is, therefore, but little rock found in this portion of the river.

In consequence of the closure of the western outlet and the elevation of the lake to a mean altitude of over one hundred feet above the sea, the outflow was diverted to the eastward over a depression in the original divide, so that this river now forms the only outlet for the drainage of the entire basin.

The physical elements which are of most importance in the consideration of the problem of water supply, lake regulation, storage and operation, have been ascertained by observation, surveys and measurements as far as possible and may be stated as follows:

Area of water surface of Lake Nicaragua	2,000,000 acres,	3,000 sq. miles.
Approximate area of entire drainage basin		12,900 sq. miles.
Maximum dimensions of Lake Nicaragua		101 x 45 miles.
Elevation of Lake Nicaragua, 98′ to 111′, mean 104½′ above mean sea level.		
Elevation of Lake Managua (above Lake Nicaragua) approximately		28 feet.
Area of Lake Managua		438 sq. miles.
Length of Rio San Juan		121.7 miles.
Extreme range of temperature on line of canal for 1898 (65° to 96°)		31 degrees.
Maximum rainfall observed at Rivas was in 1897, when it was		123.43 inches.
Minimum rainfall observed at Rivas was in 1890		31.81 inches.
The average rainfall in the basin for 1898 is found to be 28 per cent. less than that at Rivas.		

The lake is elliptical in form and has several islands. The principal one, containing the symmetrical cones of the extinct volcanoes Ometepe and Madera, rises over a mile above the lake level and affords an excellent harbor to leeward, convenient for anchorage. Near the outlet of the lake it shoals to such an extent as to require a considerable amount of dredging through soft material. No rock is found near this portion of the channel. The area of that portion of the lake extending below sea level is about 20 square miles. A steady northeast trade sweeps over the lake during a large portion of the year.

Western Division.

The lake is separated from the Pacific on the west by a strip of land about 12 miles wide with a range of hills having heights varying from 155 feet to more than a mile above sea level. The lowest point has been selected for the route of the canal, and is where a low plateau separates the drainage of the Rio Lajas, which empties into the lake, from the Rio Grande, emptying into the Pacific near Brito head. This latter is a bold, rocky promontory 248 feet high, which guards a natural bight in the coast and affords an admirable site for an artificial entrance and harbor.

The streams of this section are small and have a limited drainage, being nearly dry for five months of the year. The slope of the upper Rio Grande, however, is steep and its bed is therefore sinuous and deeply eroded. Between

Espinal and the sea, a distance of less than 11 miles, it falls about 120 feet. The topography of the valley is, however, well adapted to the purposes of a canal on either bank, or to the creation of an artificial basin by a dam closing the gorge through which the lake drainage formerly passed to the sea. The rocks on this division are sedimentary and readily worked, being loose shales and sandstones with traces of calcium. The material composing the coastal plain is a light sandy loam and easily eroded.

Eastern Division.

The country traversed by the San Juan may be conveniently divided into two sections, to wit: that portion lying above the confluence with the San Carlos, in which the deposit of sediment is relatively small, and that below, in which it is large. Further subdivisions are suggested by the topographic conditions. From the lake to the first rapids at Toro, 27 miles, the slope is gentle, being about 2½ inches per mile, while the banks are low and the adjacent swamps extensive. From the head of the Toro to the foot of the Machuca, embracing the four rapids, the fall is nearly 43 feet in 23 miles, or 22½ inches per mile. This comprises the rocky section of the ancient Continental Divide and is the gorge of the river valley. Below Machuca occurs a stretch of about 15 miles of deep water, the bottom of which extends in places to below sea level, known as the Agua Muerta (dead water). This is a portion of the old river channel not silted up by the volcanic sands brought into the lower San Juan by the San Carlos river. This sand becomes a characteristic feature of the entire lower reach of the river and its delta, from this point to the sea. It is confined, however, mainly to the bed of the channel, the banks through the hill country being the stiff clays resulting from the weathering of the rocks of the region. These banks are remarkably stable, notwithstanding the heavy rains and large volume of water which sweep past their bases at high stages.

Physics of the Stream.

As the bed of the upper river forms an important part of the route, a more detailed description of it is believed to be necessary.

The slope as given by the survey and corrected for stage may be stated to best advantage in tabular form. This, taken with the cross sections, velocity and volume of discharge as stated in detail in the accompanying reports of the assistants, will show the characteristics of the streams in a state of nature.

San Juan River Statistics.

Slopes and Distances.—Upper River.
(Lake at 105.)

Reach.	Distance, miles.	Fall, feet.	Rate of fall per mile, feet.
From the lake to Sabalos	27.16	5.4	0.198
Sabalos to foot of Toro rapids	1.70	7.3	4.294
Toro to head of Castillo	7.98	1.2	0.150
Castillo to bottom of rapids	.38	6.0	15.789
Bottom of Castillo rapids to Punta Gorda	2.08	2.5	1.202
Punta Gorda to 1 mile below Machuca rapids	10.62	26.0	2.448
One mile below Machuca rapids to Boca San Carlos	14.79	1.0	0.067
Upper river	64.71	49.4	0.763

Lower River.

Reach.	Distance, miles.	Fall, feet.	Rate of fall per mile, feet.
Boca San Carlos to San Juanillo	33.02	30.0	0.908
San Juanillo to Colorado	5.28	4.0	0.757
Colorado to sea (via San Juan)	18.65	21.0	1.128
Lake to sea	121.66	104.4	0.86

The slopes are, however, constantly varying with the stage and local conditions. In fact a heavy rainfall on the San Carlos basin may reverse the slope for a time in the Agua Muerta, causing the water to run up stream.

At Sabalos, where the slope is about 2½ inches per mile, the maximum velocities and discharges as observed were reported as follows:

Date.	Cross section, sq. ft.	Mean velocity, ft. per sec.	Discharge, cu. ft. per sec.
Jan. 21, '98..	8,819	2.16	19,000
Feb. 21, '98 .	8,576	1.92	16,530
Sept. 11, '98.	11,273	1.95	21,995
" 14, '98.	10,684	2.12	22,673
" 21, '98.	10,720	2.09	22,431
Dec. 3, '98 ..	11,273	2.39	26,700

In the upper reaches, the slope being very flat, the river carried over 20,000 cubic feet through sections of over 10,000 square feet at velocities exceeding 2 feet per second, with corresponding increase at the gorges and rapids.

Observed Maximum Velocities of San Juan.

At Ochoa station, about 69 miles from the lake, the banks are steep clay slopes. The bed of the river consists of black sand of the same character as that composing the sea beach near Greytown.

Date.	Cross section, sq. ft.	Mean velocity, ft. per sec.	Discharge, cu. ft per sec.
Jan. 8, '98...	13,100	4.00	52,400
June 28, '98.	14,462	4.25	61,410
Nov. 17, '98.	19,717	5.32	104,930
Sept. 12, '98.	10,336	4.00	41,199
" 16, '98.	12,761	4.47	57,047
" 26, '98.	9,895	4.24	41,975

From which it appears that in a state of nature the mean velocity of the stream is frequently over 4 feet per second and at times exceeding 5, while the lower river discharges over 50,000 cubic feet per second and occasionally over 100,000 without perceptible effect upon the banks.

The slopes of the stream, therefore, vary from about one inch per mile in the Agua Muerta to 6 feet in one-third of a mile on the rapids at Castillo, and the velocity from less than one foot per second to over 12, while the recorded discharge at Ochoa ranges from 16,145 to 104,930 cubic feet per second. To pass the Castillo rapids at low stages of the river a tram-way has been constructed under the brow of the hill for the purpose of transferring passengers and freight. The width of the upper river is quite variable. Its narrowest limits are about 350 feet, while in some places it widens out to 1200 feet. Its general alignment is direct, but there are several sharp horseshoe curves where cut-offs would be required across alluvial flats by which over 4 miles of distance would be saved.

The Lateral Drainage.

The principal tributaries from the Costa Rican side are the Rio Frio, Poco Sol, San Carlos and Sarapiqui, the former emptying into the lake just at the head of the river. These large streams exert a controlling influence in confining the location of the canal to the left bank. The streams on the left bank are the Melchora, Palo de Arco, Negro, Sabalos, Machuca, La Cruz, Machado, Danta, San Francisco and others, none of which have a large drainage basin. They have many small branches permeating the swamps and ravines which characterize the broken topography of this section.

On reaching the edge of the coastal plain the river drainage is distributed through the San Juanillo, Colorado, lower San Juan, Taura and their branches, Parado and Caño Bravo, leading to the sea.

The minimum computed discharge of the

upper river at the Sabalos station during 1898 was found to be 11,206 cubic feet per second on May 13, while the maximum occurred on November 13, when it was 28,490 feet, the difference in stage being 3.55 feet. At Ochoa, below the mouth of the San Carlos, the minimum computed discharge on May 10 was 16,300 and the maximum was 107,000 cubic feet per second on November 17, the variation in stage being 13.35 feet. To provide for extreme cases, however, it is estimated that the river above the San Carlos may, at rare intervals, under the cumulative discharges from the lake and river, reach a possible maximum of 100,000 second-feet and that the San Carlos, a flashy and torrential stream, may add 100,000 more to this quantity in the lower section for a short time.

The Capacity of the Channel.

The entire river bed has been carefully surveyed with a view to determine its carrying capacity under the regimen resulting from the creation of such dams and locks as may be found best adapted to convert it into a navigable channel for deep draft vessels. The upper river will require dredging from the lake to the Castillo rapids, and as the channel as proposed will be 300 feet wide at bottom and extend to a depth of 30 feet below the lowest lake level, this cut will largely increase the cross section and thus enable a larger volume to be discharged without any material increase of velocity. Moreover, the river falls about 13.9 feet below the 105 stage in the lake before reaching the head of the Castillo rapids so that a dam farther down stream impounding this water would still further augment the cross section by raising the surface. As the capacity is regulated by the smallest sections, it is necessary to ascertain their location and effects upon the discharge under the new regimen.

The Controlling Section.

Under existing conditions the ruling sections of the stream are found to be at stations 1494 and 1515 near the head of the Toro rapids and Castillo rapids, in that section of the upper river between Fort San Carlos and the Castillo Viejo, as indicated below. The relation of the existing cross section of the stream to that of the improved section when raised to the upper level of the lake and dredged to the requisite depth of 30 feet with a bottom width of 300 feet, is stated in square feet and percentages.

Relative Areas at Controlling Sections.

Location. Station.	Miles.	Original area, sq. ft.		Enlarged area, sq. ft.		Percentage of increase.
268	5	7,810		15,200	Minimum.	94.6
680	13	7,697		15,920		94.0
1,265	24	7,960		17,200		116.0
1,494	28¼	2,948	Minimum.	21,840		641.0
1,515	28¾	3,758		32,824		775.0
1,665	31½					
Castillo,		6,435		23,406		264.0
Lower Machua,		6,060		44,370		632.0

From this it appears that the location of the controlling section would be changed from its present position to a point 5 miles from the lake, while the area of that section would be very nearly doubled at a lake elevation of 110 feet above tide. As the maximum discharge required to pass through this section, with a range of 6 feet for the greatest fluctuation, would not produce velocities exceeding 3.3 feet per second, such a discharge would not materially affect the stability of the channel nor its navigation. A further discussion of the resulting velocities under different volumes of discharge is submitted by Mr. F. L. Stuart, Assistant Engineer, showing that at no other place in the channel would the velocity be as great.

Computed Velocity in River and Canal at Various Points, with Different Discharges, referred to Lake at 110:

Location.	Discharge, 30,000 cu. ft. Velocity, ft. per sec.	Discharge, 50,000 cu. ft. Velocity, ft. per sec.	Various Discharges, cu. ft. per sec.	Velocity, feet per second.
Sta. 268 in River,	1.9	3.3	55,000	3.6
			35,000	2.3
Sta. 680 in River,	1.9	3.1	60,000	3.7
			40,000	2.5
Sta. 1265 in River,	1.7	2.9	70,000	4.1
			50,000	2.9

Cut-Off Palo de Arco to Isla Grande.

Surface of Water 110.

Location.	Discharge, 30,000 cu. ft. Velocity, ft. per sec.	Discharge, 50,000 cu. ft. Velocity, ft. per sec.	Various discharges, cu. ft.	Vel.	cu. ft.	Vel.
In River,	1.16	1.86		2.4		1.66
			62,500		42,500	
In Canal,	1.3	2.2		2.8		1.86

Cut-Off Sombrero de Quero to Santa Cruz River.

Surface of Water 110.

Location.	Discharge, 30,000 cu. ft. Velocity, ft. per sec.	Discharge, 50,000 cu. ft. Velocity, ft. per sec.	Various discharges, cu. ft.	Vel.	cu. ft.	Vel.
In River,	1.4	2.3		3.56		2.3
			75,000		50,000	
In Canal, bot. 150	2.3	4.00		5.9		4.0
In River,	1.03	1.72		2.56		1.72
			75,000		50,000	
In Canal, bot. 250	1.9	3.23		4.86		3.23

Cut-off 2 miles west of Boca San Carlos.

Surface of Water 110.

Location.	Discharge, 30,000 cu. ft. Velocity, ft. per sec.	Discharge, 50,000 cu. ft. Velocity, ft. per sec.	Various discharges, cu. ft.	Vel.	cu. ft.	Vel.
In River,	0.6	1.0		2.01		1.6
			100,000		80,000	
In Canal,	0.7	1.18		2.36		1.8

2 Dams Above Cut-Off, 8-Lock System.

Surface of Water 82.4.

Location.	Discharge, 30,000 cu. ft. Velocity, ft. per sec.	Discharge, 50,000 cu. ft. Velocity, ft. per sec.	Various discharges, cu. ft.	Vel.	cu. ft.	Vel.
In River,	0.8	1.35		2.7		—
			100,000		—	
In Canal,	1.23	2.1		4.1		—

2 Dams Above Cut-Off, 6-Lock System.

Surface of Water 73.2.

Location.	Discharge, 30,000 cu. ft. Velocity, ft. per sec.	Discharge, 50,000 cu. ft. Velocity, ft. per sec.	Various discharges, cu. ft	Vel.	cu. ft.	Vel.
In River,	0.83	1.39		2.77		1.2
			100,000		80,000	
In Canal,	1.30	2.17		4.33		3.45

This table further demonstrates that instead of having velocities exceeding 12 feet per second over the rapids, which would be submerged, the maximum current in the river under a discharge of 30,000 cubic feet would not exceed 2 feet or $1\frac{1}{3}$ miles per hour, which would not readily disturb the banks of this section of the stream. Under ordinary conditions and throughout nearly this entire reach the velocities would be less than one foot per second.

With a discharge of 50,000 cubic feet, which is higher than will probably ever be reached in this (upper) part of the river, the maximum velocity through the controlling sections would not therefore much exceed 3 feet per second, imposing no material restrictions on navigation.

Stability of Slopes.

Nature's Compensations.

So much stress has been laid upon the excessive precipitation and its destructive effects upon the proposed works, as well as upon the labor and machinery required, that the Commission is impelled to call attention to the fact that the

physical features of the country furnish the most convincing and conclusive evidence that these uncontrolled forces are not so injurious as has been alleged, for the angle at which freshly made earth-slopes stand is found to be much steeper than that prevailing in our more northern latitudes, where they are also exposed to the destructive action of frost and the internal stress due to greater ranges of temperature. In some cases in the northwest the range covers 160 degrees, whereas in Nicaragua the greatest fluctuation seldom exceeds 25 degrees. The absence of frost more than compensates for the excessive downpour.

Observations by engineers of experience in tropical countries, lead them to believe that the same security and greater permanency may be obtained with less first cost and economy of maintenance by making the side slopes steeper and thus reducing the prisms of cut and fill, than by employing the typical sections of our own latitudes. Nature compensates for the greater rainfall by the uniformity of heat and moisture. The spontaneous growth of vegetation revets the natural surface, clothing it with a protecting thatch which not only acts as an elastic cushion to break the impact but also to retain the water and thus prevent the sudden and destructive floods so familiar to us during the spring, when the rain and melting snows combine to produce their maximum effects.

The Board of 1895, in referring to the character of the work done in Greytown harbor, remarks that "The material excavated was almost entirely volcanic sand, similar to that of the beach. . . . When piled in heaps it forms a porous mass through which the torrential rainfalls descend with surprisingly little effect upon its contour, even though the slopes be steep. This feature was noted both in the mounds of dredgings near the entrance and in the canal banks, where the sands dropped from the dredge chutes still stood seemingly undisturbed since they were put there."

Of the cuts along the railroad the Board also adds: "The cuts have heights up to 20 feet, with slopes from vertical to 45 degrees, and in most cases stood with an extraordinary stability under the tropical downpours. At several, the original tool marks were still visible, both picks and steam shovel. In several others, there had been slides, but none of great extent. The ditches were generally clean and in but few points had wash reached the rail. The surface of the cuts was in some cases protected by vines, but in most was quite bare unless for a minute lichen.

"As these clay cuts have been exposed for over three years to the severest rainfall of record on this continent and were found in better condition on the whole than an exposure in the United States for a single winter would have left them, it is evident that the absence of frost more than balances the tropic downpour and for the material in question constructions can quite as safely be designed as in the United States. . . . The natural growth in the road-bed was unexpectedly slight, although in two or three cases the canebrakes had invaded the track.

"On the whole, taking into account the condition of the sand dumps at Greytown and of the clay cuts and fills on the line of the railroad, it is evident that the heavy rainfall is not necessarily as formidable an obstacle to outdoor construction as might be supposed."

The Geologist, Dr. Hayes, also states, concerning the resistance of the slopes to abrasion on the western division, that

"The present channel of the Rio Grande is from 15 to 25 feet in depth and its sides are gen-

erally steep, often nearly or quite vertical. They serve to show the capacity of the material to stand at very steep slopes. It would also probably form fairly impervious embankments."

There is no reason, therefore, for departing from the usual engineering practice, unless it be to make the slopes steeper and thus reduce the cube of excavation and the consequent cost of the work.

Sanitary and Climatic.

The impression that this portion of the isthmus is unusually unhealthy, is erroneous. On the contrary, the local conditions are such that with ordinary hygienic precautions the risks from disease are slight.

The frequent rainfall on the east coast furnishes an ample supply of fresh, soft water condensed directly from the clouds; the porous sandy soil absorbs it so rapidly as to prevent stagnation, while animal refuse is quickly removed by the scavenger birds and fish continually on the alert for food.

With their light, loose clothing, vegetable diet and cleanly habits, the natives seldom suffer from fevers. Even our unacclimated Americans passing from a rigorous winter temperature to the mild region of the trade winds were, with few exceptions, exempt from febrile complaints, and amongst the large number of engineers sent out there was no mortality in the country. The constant motion of the wind, sweeping through this low divide, appears to remove the noxious exhalations which characterize other portions of the isthmus. Yellow fever finds no habitat at Greytown and even when imported it does not become epidemic. Abstemious habits and careful police of camps will insure as good health amongst laborers as will be found in many localities in this country. The climate would affect the labor question, therefore, chiefly by the lassitude resulting from its enervating influence.

Assistant Engineer Stuart says that, "The atmospheric conditions are excellent, and for the seven months we were in the field, we worked in all conditions of weather, losing but one entire day on account of a heavy downpour of twelve hours."

The narrow limits within which the temperature ranges are shown from a few selected observations at various stations during the year as below. The Rio Viejo station is located on the western slope of the Cordilleras east of the lake and at a higher altitude than the others. Hence its greater range of 30°. This uniformity of temperature is one of the important factors in the consideration of the permanency of important works as well as in the health of the inhabitants.

Exhibit of Extreme Range of the Observed Temperature in Nicaragua.

Location.	Date, 1898.	Maximum.	Minimum.	Date, 1898.	Range.
Brito and Tola Stations	Dec. 22,	88° F.	75° F.	June 28,	13°
Las Lajas Station	May 12,	91° F.	73° F.	Sept. 10,	18°
Rio Viejo Station	Mar. 3,	97° F.	62° F.	Mar. 12,	35°
Fort San Carlos Station	May 8,	91° F.	70° F.	Mar. 28,	21°
Sabalos Station	Mar. 20,	90° F.	65.2° F.	Dec. 25,	24.8°
San Carlos River	May 7,	95° F.	66° F.	Feb. 7,	29°
Ochoa Station	Oct. 1,	95° F.	66.5° F.	Jan. 3,	28.5°
Deseado River Station	May 25,	91° F.	65° F.	Jan. 3,	26°
Greytown	Sept. 29,	96° F.	69° F.	Mar. 14,	27°

Earthquakes and Volcanoes.

From the most reliable data obtainable the Commission believes that the canal region is practically exempt from any seismic influences of sufficient force to cause destruction or danger to any part of the canal route or suspension of its traffic. Dr. C. W. Hayes has treated this question fully in his report.[1] He says that:

"Earthquakes due to the dislocations of strata (faults) are perhaps no more liable to occur in the vicinity of the Nicaragua Canal Route than elsewhere, and hence they do not constitute a danger which is peculiar to this region more than to almost any other in which a ship canal might be constructed."

He then proceeds to discuss those due to volcanic agencies at some length and concludes that those activities are on the wane and so remote from the route as not to constitute a menace. In quoting from Major Dutton, he adds:

"Briefly, then, the risk of serious injury by earthquakes, to the constructions proposed for the Pacific section of the canal is so small that it ought to be neglected; . . . also that the risks to the Atlantic section are still smaller than those to the Pacific section."

Materials for Structural Purposes.

The cost and durability of the canal are also affected by the character and distribution of such native material as may be utilized for the purposes of construction. These consist chiefly of earth, rock, timber and sand, all of which are abundant and free. Cement, iron, explosives, tools, plant, and some provisions and clothing will need to be imported but will be exempt from duty.

Alluvium.[1]

"All unconsolidated material which has been transported and deposited by streams is classed as alluvium. . . . It varies considerably in composition, depending upon the source from which it was derived and the manner in which it was deposited. It varies all the way from coarse, clean-washed sand or gravel to the finest clay. It may for convenience be separated into three sub-classes, (1) sand, (2) silt, a variable mixture of fine sand and clay, and (3) clay-silt, composed chiefly of clay, with little or no sand. All three sub-classes contain variable quantities of vegetable matter.

"The alluvium is everywhere of such character that it can be easily handled with dredges. Almost everywhere the silt and clay-silt are sufficiently solid to stand at moderate slopes, the slope of one on one probably being sufficient. In some cases, as in the Florida lagoon, special precautions may be needed to preserve the slopes. The material becomes very hard when dry, and even when it is piled up so that the water can drain off it becomes comparatively firm. This is shown in the vertical stream banks where drainage is possible, while the same material forms a soft mud in the swamps at some distance from the stream channels. The black sand when free from clay is, of course, quite pervious to water and would not be suitable for banks where the water level was permanently different on its two sides. This material, however, will not be encountered beyond the site of the first lock on the proposed low-level line. It is probable that wherever the canal is more than half in excavation the silt will form banks sufficiently impervious to hold the required height of water without the addition of any other material. Where the head is greater than fifteen feet it may be necessary to add a puddled core to the bank unless the latter is made of more than ordinary thickness."

Sand.

The black volcanic sand of the east coast and lower river section is not composed of the partly

[1] See Report of Dr. Hayes, Appendix II.

decayed minerals derived from a deeply weathered rock, but is made up entirely of finely comminuted fragments of fresh volcanic rock evidently broken up and ejected by explosive volcanic eruptions. It would thus make a good, sharp, clean material for hydraulic mortar, concrete or béton. Its specific gravity is 1.68 or 104 lbs. per cubic foot, comparing very favorably with the best building sand in the United States.

Clay.

Clay of excellent quality is abundant and well distributed. When mixed in suitable proportions with sand and gravel, it makes an admirable puddling material.

"Quartz occurs in only a few of the rocks, so that much of the clay is remarkably free from grit, tough and compact. Although it is penetrated by numerous roots and burrowing insects, the absence of frost permits it to remain more compact than any surface clay in higher latitudes. Next to the silt it will form by far the largest part of the excavation. It will make perfectly impervious embankments if some means are taken to puddle it as it is deposited, but probably if simply dumped in the bank it would be pervious to water."[1]

Wood.

Numerous large trees occur in the forests along the river and on the border of the lake, which are denser and stronger than our American oaks and pines. The clearing of the canal route will also furnish a large number of cross-ties. Some of these native woods, according to Col. Childs, will last above ground from forty to fifty years. The Madera Negra is one of the most valuable for ties and is abundant. It may also be obtained for dimension timber up to thirty-foot lengths and eleven inches square.

The Nispera will cut in lengths of fifty feet and square eighteen inches. It is very common and durable, but heavy. Many other varieties exist, as the Palo Cortez, Guachipilin, Roble, Cocobole, Pine, Cedar, Niambaro, Caoba or Mahogany, Palo-de-Arco, Granadillo, Guyacan, Almendro, Feniscaro, etc. The shipment of timber is one of the industries of the port of San Juan del Sur. As much of the native timber is valuable for export and as no mills exist for its local manufacture, it may doubtless prove more expedient to import the piling and dimension material from the extensive forests of the Southern States and to use the local product mainly for fuel and ties.

Shelter.

There is also ample material available without cost, for the protection of men and materials from the rain and sun. The usual habitations of the natives consist of a carefully laid thatched roof, substantially built, reaching nearly to the ground, with walls of bamboo or adobe. These afford free circulation of air and are cool and dry. Their only cost is for the labor of erection, which is slight.

The fuel in general use is wood, which is cut and stacked under shelter on the banks of the river. A considerable quantity of cord wood can be secured from the clearing of the route and adjacent forests. In some localities water-power may be made available.

Iron and Steel.

These metals will necessarily be imported, but the climatic conditions are such as to cause remarkably little deterioration. Templates of the rails which have been exposed to the rain and sun

[1] See Report of Dr. Hayes, Appendix II.

for about nine years do not exhibit any measurable loss in section of weight. The spikes also retain the sharp edges of the tool marks on their heads and shanks. Only where the salt water of the ocean reaches the iron rails and bolts on the pier is there any considerable amount of scale visible.

STONE.

A large amount of material on the route of the canal, classified as rock and soft rock, will require excavation to create the channel. A portion of this is suitable for structural purposes. On the western division the rock is generally a calcareous non-fissile shale, interstratified with beds of sandstone varying from a few inches to two or three feet in thickness. The shales constitute the greatest bulk of the rock to the eastward of Brito Head, where the sandstones of the northern headland are too thin for use as building stones but are suitable for concrete or rip-rap.

About half a mile east of Brito, however, is found a group of heavy sandstone beds forming a spur extending into the Rio Grande valley. "These beds would probably yield a good quality of dimension stone; would be easily quarried in dimensional blocks up to 20 or more inches in thickness; would dress readily and be as durable as the average sandstone." [1]

North of the canal line at Buen Retiro is a large deposit of intruded andesite or trap which makes a very desirable material for structural purposes.

"It is probable that all the material on the west side which has been classed as soft or disintegrated rock can be excavated with a steam shovel without blasting. The material stands in natural slopes of 60° or more (to the horizontal) and artificial slopes equally steep will probably be entirely safe." [1]

[1] See Report of Dr. Hayes, Appendix II.

The rocks on the eastern division are chiefly of igneous origin, but from a few miles below Castillo to half-way between Machuca and Boca San Carlos they are largely sedimentary with a few small igneous dikes.

No coarse conglomerates nor pure limestones have been discovered in this formation, although they may occur. "The beds of massive sandstone exposed on Machuca creek being to a large extent free from joints could probably be quarried for dimensional building stone, which would be easily worked and fairly durable." [1]

The principal varieties of the igneous rock found in this section are *augite-andesite*, *olivine basalt*, *hypersthene basalt* and *dacite*. The first three are commonly known as *trap* rocks. They are generally compact and heavy. The dacite is lighter than the trap and somewhat softer. (This was called conglomerate by the Canal Company.)

The basalt (trap) extends from the Boca San Carlos eastward beyond the San Francisco hills, forming the Sarapiqui hills and others bordering the lower portion of the San Juan river as well as those in the vicinity of Silico lake, and is suitable for dams, jetties and concrete.

The dacite is found at lower Ochoa and Tambor Grande, where it comes to the surface and continues to the Eastern Divide. It is there interbedded with the andesite tuffs and basalt.

Associated with the above-named massive rocks is a group of fragmental igneous rocks whose members vary from coarse conglomerate or breccia to beds of fine volcanic ash. The coarser varieties resemble in their physical properties the igneous rocks from which they are derived, while the fine ash is generally talcose and crumbles on exposure to the air.

Deposits of hard rock also exist near the site of Lock No. 1 of the Canal Company's line to which the railroad has been built.

Several outcrops of rock reported to be suitable for jetty construction exist on the coast at Point of Rocks and at Monkey Point, but no samples from these ledges have been secured. The quarries are readily accessible from the sea and furnish material for ballast to coasters.

Classification and Weathering.

"The three classes of materials—alluvium, residual clay and soft rock—should be considered as earth in making estimates for excavation. The soft rock, however, may require some blasting, particularly toward the bottom and where it contains very large boulders. It will stand with much steeper slopes than the silt and clay and will be less liable to slip. Not being plastic, it will also support a heavier load, and hence may be relied upon for foundations where the weight of the structure is not excessive. For these reasons it seems desirable to make the distinction between clay and soft rock wherever possible." [1]

The weathering of rocks is brought about by two processes—rock disintegration and rock decay. The first varies directly and the second inversely with latitude when humidity is constant. The first process depends on changes of temperature and expansion of interstitial water by freezing, hence is inactive in the tropics. The second process depends on high temperature and a rapidly decaying vegetation, hence is active in the tropics. Special attention is directed to the fact that it is chiefly the first process of disintegration which is inimical to the permanence of structures, and hence that their relative durability will be greater in the tropics than in higher latitudes.

Such being in brief the physical conditions of the route, it remains to determine the dimensions, which, all things considered, will best subserve the interest of the world's commerce in making this transit of the isthmus.

[1] See Report of Dr. Hayes, Appendix II.

Dimensions of Canal.

To provide ample facilities for the safe and expeditious passage of vessels, the trunk of the water-way has been considerably enlarged over that of any previous project. The dimensions adopted by the Commission as the basis of the estimates are as follows:

The canal nowhere to be less than 30 feet in depth. The width varying with the local conditions as follows: From Greytown harbor to Boca San Carlos the bottom width to be 150 feet with slopes in earth of 1 : 1 and in alluvial silt of 1 : 2. In hard rock vertical sides up to 40 feet from the bottom, then slopes of 5 : 1. In soft rock the slopes to be 2 : 1.

In the river the width at bottom to be 300 feet, with slopes of 1 : 2 with enlargements at the bends, and at the eastern end of the lake the excavation to be 600 feet wide at the outer end, decreasing to 300 feet at the river, and having slopes of 1 : 5 to the depth of 6 feet and then 1 : 3; for all routes from the Caribbean sea to the lake, excepting the Menocal route, the same dimensions are used. The bottom width of the canal from the lake to the Pacific to be 150 feet, with slopes as on the east side, and the computations have been based upon a minimum lake elevation of 104 feet above mean sea level, Caribbean sea, as a datum. The minimum radius is limited to 3000 feet with enlargements of width in bends varying according to the degree of curvature.

The locks are 80′ x 30′ x 665′ between quoins, giving an available length of 620 feet with variable lifts.

Estimates were also made upon numerous modifications of the above dimensions.

For convenient reference and comparison with the canal prism as proposed by the Maritime Canal Company, the areas of the several cross sections and the percentages of increase are stated herewith:

	Area of cross sections in square feet.	Per cent. of increase.
Between jetties, Greytown,	23,400	
Entrance to harbor, Greytown	14,700	
Coastal section	6,300	10.3
Canal proper	5,400	9.1
Through rock	4,500	50.0
In the river (in rock)	9,900	131.0
In the river (in earth)	10,800	84.0
In the lake	7,272	73.0
	13,272	216.0

WEST SIDE.

	Area of cross sections in square feet.	Per cent. of increase.
Western Divide	4,500	50.0
Across coastal plain	5,850	8.0 less

Distances along the line of the Canal route proposed by this Commission from the seven-fathom curve in the Pacific ocean to the seven-fathom curve in the Caribbean sea:

	Miles.
1. Brito Harbor	0.93
2. Brito to Buen Retiro	8.12
3. Buen Retiro to west side of lake	8.71
4. Lake Nicaragua	71.34
5. East side Lake Nicaragua to Boca San Carlos	56.96
6. Boca San Carlos to Sarapiqui	21.59
7. Sarapiqui to Greytown	20.59
8. Greytown Harbor	1.74
Total	189.98

Regulation of the Lake Level.

All plans for a canal by the Nicaragua route contemplate using the lake as the summit for the canal and as a feeder. The regulation of its level is therefore a matter of the greatest importance.

It is known with reasonable certainty that the lake has varied in its elevation above sea level as much as 13 feet. It has probably been as low as 98 feet above mean sea level and as high as 111 feet above the same plane. These extremes have occurred at relatively remote intervals, but their occurrence must be admitted, and their recurrence in the absence of regulating works must be reasonably anticipated. It is also known, as a result of the observations of 1898, that notwithstanding the losses due to the outflow through the San Juan river and to evaporation, the lake has risen as much as two feet in six weeks.

The higher the lake is held the less will be the excavation in the upper level, and as this is a heavy item in the cost of construction, the effort has always been to keep that level up as high as practicable, without causing unnecessary damage to private property. On the other hand, a spillway of capacity sufficiently great to prevent the lake from rising is expensive. The problem, therefore, is how best to meet the varying conditions. A careful investigation has been made of the discharge of all streams of importance, measurements of rainfall observed at points widely distributed throughout the basin, and the rate of evaporation from the lake surface determined.

The area of Lake Nicaragua, in round numbers, is 3000 square miles, nearly 2,000,000 acres. The drainage area, including both lakes, is about 12,900 square miles. During the dry season of 1898 measurements were taken to determine the total inflow into Lake Nicaragua, which was found to be only about 1700 cubic feet per second, showing that in the dry season

the inflow into the lake is very small, scarcely worth considering. Nearly all the streams showed evidences of being stagnant several months, yet the year 1898 was one of more than average rainfall.

Rainfall.

Observations to determine rainfall have been kept at Rivas for the last 19 years. During the year 1898 observations were taken at several scattered stations in the drainage basin to determine the rainfall of the lake region. These records are given in the accompanying appendices.

Comparing the records at Rivas for the year 1898 with those for the other points, it will be noted that the rainfall at Rivas was greater than the average for other parts of the basin; that at Rivas being 108 inches and the average in the basin 78 inches, a difference of about 28 per cent. in favor of Rivas. This might at first appear anomalous, but it may be accounted for by the peculiar topographical features of the country in connection with the prevailing winds. It will therefore be assumed that, in order to obtain the rainfall in the basin for other years than that of 1898, the Rivas record will have to be reduced by 28 per cent. The number of observation stations in the basin are not great, but they offer a basis for estimating rainfall in those years for which there is no other record than that of Rivas.

There are two distinctly marked seasons in the drainage area of the lake—the wet and the dry. The latter begins about December 15 and lasts until about May 15, a period of five months. The wet season then begins and lasts until December 15 following. This period has a duration of about seven months. It is probable, however, that the length of the wet and dry seasons may vary in some years, but it is well understood among the people in that region that those are the dates from which they are reckoned, and the observations for the year 1898 confirm this.

Evaporation.

The amount of evaporation as determined for the year 1898 was 52 inches. That year was an abnormally wet one and it is therefore probable that the evaporation was somewhat below the average. Mr. Davis estimates a normal annual aggregate at about 60 inches, or five feet. The amount of evaporation in the lake itself is greater during the dry and less in the wet period. It has been taken at 4 inches per month during the wet period, and 6 inches during the dry, which corresponds closely with the observations for 1898.

These results have been checked by the Commission's study of the exhibits, as follows:

From Plate XVIII, Appendix III, it appears that during the year of 1898, throughout which careful observations were made, the lake fell about 3.09 feet between January 6 and May 15, a period of 131 days or 4.5 months, while in the following season of rainfall it rose 4.72 feet by December 5, when it again began falling. The net gain in storage during this entire year from January 5, 1898, to January 5, 1899, was 15.6 inches.

It will be observed that during that portion of the season beginning February 1 and ending May 15 the lake surface declined uniformly (the slight fluctuations being due to wind and not to rainfall), and that in this time the total rainfall did not exceed $2\frac{3}{4}$ inches over the lake surface. The run-off from the parched ground at this season is practically zero. Hence the only gain was the direct rainfall while the losses were those

due to evaporation and outflow, which latter quantity was measured by continuous observations at the Sabalos station on the San Juan river, the only outlet.

The outflow between February 1 and May 15 is given as 2,817,748 acre-feet, equivalent to a vertical depth over the lake area (2,000,000 acres) of 1.408 feet. If this be deducted from the loss in storage and rainfall, which is 2.840 feet, it leaves 1.432 feet loss due to evaporation in 104 days, or a diurnal rate of .165 inch ($\frac{1}{6}''$), or 5 inches per month, or a rate of 5.00 feet per annum for a dry year. This being deduced during the dry season would doubtless represent the maximum for the year.

Run-off.

The run-off or inflow to the lake, from rainfall on its drainage basin exclusive of the lake proper for the year 1898, has been found to be about 30 per cent. of the rainfall. This is computed as follows: The average rainfall at six stations in the basin of Lake Nicaragua for 1898, was 78.29 inches. During that year the lake rose 18 inches. The outflow if held would have raised the lake 84 inches. Evaporation as determined was 52 inches, so that if there had been no outflow nor evaporation the lake would have risen 154 inches. Of this, 78.29 was by direct fall on the lake, leaving 75.7 inches as the rise due to the fall on the land, or the run-off. The area of the lake is 3000 square miles; the area of the tributary basin is 9900 square miles. The latter is, therefore, 3.3 times that of the former. Dividing the inflow into the lake, 75.7 inches, by 3.3, the ratio of the lake surface to the exterior drainage, we have 22.94 inches as the rise due to run-off. This is 29.3 per cent. of the rainfall.

Lockage.

When the canal is built, the lake will be drawn upon for water for lockage and for power. There will also be some leakage, the amount depending largely on the kind of dams and waste-ways used. The estimate for leakage is necessarily arbitrary, but a computation based on large traffic through the canal gives three inches as the estimate for annual requirements for lockage, leakage and power.

Regulation.

The surface of the lake is acted upon by several opposing forces. They must be so regulated that its fluctuations can be controlled within proper limits. Evaporation, outflow and use of the canal will lower the lake's level. Rainfall and inflow will raise it. Water must therefore be stored for evaporation and use, and the excess of rainfall and inflow be discharged. For purposes of storage against evaporation years of minimum rainfall must be considered, and for determining spillway capacity years of maximum rainfall.

The data for an absolute determination of these problems would necessitate a series of observations extending over many years. But with the records for 1898 in connection with the rainfall records of Rivas for the past 19 years, conclusions may be reached which, while they may not be absolutely correct, will be sufficiently close for all practical purposes.

The year of minimum rainfall, as determined by the Rivas record, is 1890. During that year 31.81 inches of rain fell. If this be reduced by 28 per cent., the difference between Rivas and the average of other parts of the basin, we have 22.9 inches as the average for the basin in an extreme dry year. It is well known that variations in annual rainfall are greater at sin-

gle stations than over an extended area. It is therefore probable that this estimate is too low for a very dry year. Twenty-eight inches have, therefore, been assumed as the minimum annual rainfall in the basin.

The estimated run-off for 1898 was 29.3 per cent. of the rainfall, and as the run-off will diminish with the diminution of rainfall, 25 per cent. of the rainfall has been taken as the average for a dry year. We then have 28 inches falling directly on the lake and 28 inches on the drainage area tributary thereto. The latter being about 9900 square miles, enough water would fall on the land to raise the lake 23.1 inches. This added to that falling direct would raise the lake 51.1 inches if all sources of loss were cut off. But the loss from evaporation would be about 60 inches, and three inches would be lost by lockage, leakage and use—a total of 63 inches, or 5 feet and 3 inches. There would then be a deficit of 11.9 inches at the end of the year. If the year ends with the end of the wet period, the succeeding dry period will be begun with this deficit. For this period, lasting about 5 months, during which the lake would receive practically no rain, and evaporation would be at the maximum, the loss to the lake would be 30 inches for evaporation and $1\frac{1}{2}$ inches for lockage, leakage, etc., total loss $31\frac{1}{2}$ inches, which, added to the deficit of 11.9 inches, gives 43.4 inches as the deficit at the beginning of the wet season, when the lake would probably fill up again. Temporary storage of about 4 feet in the lake is therefore needed to provide for evaporation and use in a time covering two dry periods and one wet one. In other words, if the lake had been at 108 at the beginning of the first dry period, it would have fallen to 104 at the end of the succeeding dry period.

Substantially the same result is reached by Mr. Wheeler in another way (see his report).

In a year of maximum rainfall and minimum evaporation the conditions are reversed. The problem will be to get rid of surplus water and prevent the lake from rising to a high level.

The year of maximum rainfall, according to the Rivas record, was in 1897, when 123 inches fell. Reducing this by the 28 per cent. ratio, we have a rainfall in the basin of 88.6 inches for the maximum year. As before stated, the variation in annual rainfall over a large area is not as great as it is at one station. It is therefore probable that for the entire basin this estimated rainfall is too great. Suppose it be taken at 84 inches, or 7 feet, there results:

Rainfall direct on the lake..	84	inches
Run-off, 30 per cent., about.	84	"
Total inflow.....	168	"
Deduct for evaporation and use	63	"
	105	" = 8′ 9″

This represents what must be taken care of by storage and discharge.

This rainfall will not be extended uniformly over a year, but most of it will fall within the wet season of seven months. A mean discharge of about 40,000 cubic feet per second would discharge it all in this time Or, if four feet be stored in the lake, a mean discharge of 22,000 cubic feet per second would take care of it. Inasmuch as it is impossible to know in advance whether the rainfall of a season is to be heavy or light, it will not be safe to begin discharging at the full capacity of the outlet until enough water has been stored for possible deficiencies. Consequently, instead of having seven months' time in which to discharge the surplus, a large part of it might have to be discharged in a less time, and a spillway of greater capacity would be

needed. With a spillway capacity of 50,000 cubic feet per second the entire surplus could be handled in about 92 days.

The following method is used by Mr. E. S. Wheeler for determining the amount of water to be taken care of in years of maximum rainfall:

"Between June 18 and October 29, 1898, a period of 132 days, the rainfall at Rivas was 76.36 inches; the lake rose 48.00 inches; the outflow lowered it 32.76 inches and the evaporation of the lake surface lowered it 16.38 inches. Therefore, if there had been no evaporation on the lake nor outflow from it, it would have risen 97.64 inches.

"Between May 17 and October 27, 1897, a period of 164 days, the rainfall at Rivas was 112.42 inches. This was the period of greatest rainfall shown in the Rivas records since 1879. The amount of fluctuation in the surface of Lake Nicaragua caused by this rainfall was not observed; an attempt will be made to determine it by comparison with the wet portion of 1898, when both fluctuations and rainfall were carefully measured. The problem may then be briefly stated as follows: If a rainfall of 76.36 inches in 132 days would cause a rise in the lake surface of 97.64 inches, what rise would be caused by a rainfall of 112.42 inches in 164 days? The ratio between rainfall and change in lake level, as given in the preceding table, cannot be used for this problem, because in this case only portions of a season are considered. At the beginning of these periods the streams and marshes were drained and empty; at the end they were overflowing and the entire runoff due to the rainfall had not yet occurred. Therefore, this problem must be solved as a special case. If the rise was exactly proportional to the rainfall it would be 143.7 inches, provided there was no evaporation on the lake or outflow from it. It is, however, probable that in this case as in the preceding one, the greater daily rate of rainfall in 1897 would cause the lake to rise slightly more than the proportional amount. An examination shows that the daily rate of rainfall in 1897 was 18 per cent. greater than in 1898. Using the ratio as before, the rise in the lake would be 22 per cent. greater. Applying this per cent., the computed rise in the lake for 1897 would be increased from 143.7 inches to 148.58 inches. This, then, is the estimated amount of fluctuation that would have occurred during the period of greatest rainfall of the last 20 years if there had been no evaporation on the lake or outflow from it.

"The question as to what amount of fluctuation in the lake will be necessary to take care of this rainfall will next be considered. The estimated rise of 148.58 inches must be provided for by evaporation, outflow and temporary storage in the lake.

"Assuming the ratio of evaporation from the lake surface to be the same as in 1898, it would for the 164 days amount to 20.97 inches. Subtracting this from 148.58 inches leaves 127.61 inches that must be provided for by the outflow and temporary storage.

"The lake has an area of 3000 square miles; a rise in its surface 127.61 inches would be equivalent to 889,408,618,000 cubic feet. If this should run out of the lake in 164 days the mean discharge would be 62,769 cubic feet per second and there would be no change in the elevation of the lake surface. If the lake should be permitted to rise one foot then the mean discharge would be reduced to 56,866 and each additional foot that the lake is allowed to rise will reduce the mean rate of discharge by an equal amount. The following table shows the

required rate of discharge for each foot of fluctuation:

0	feet	require	62,800	cubic	feet	of discharge.
1	"	"	56,900	"	"	"
2	"	"	51,000	"	"	"
3	"	"	45,100	"	"	"
4	"	"	39,200	"	"	"
5	"	"	33,300	"	"	"

"It appears from this table that if a waste-way having a capacity of 33,000 cubic feet per second be provided, the fluctuation in the lake could be limited to five feet for rainfall as great as any that has occurred in the last twenty years.

"Since the canal itself will incidentally provide waste-ways exceeding this in capacity, it appears that not more than five feet of rise will be caused by the largest rainfall. Therefore, no addition need be made to the six feet already provided for dry periods."

The Commission has therefore concluded that in any plan of a canal by the Nicaragua route a spillway of 50,000 cubic feet per second capacity should be provided, and that the lake may vary in its level from elevation 104, the minimum, to 110, the maximum.

The endeavor would be to approach the dry season with the water level of the lake at about 108, and during that dry season to draw it down to 106 if it did not go to that level from natural causes. At the beginning of the wet season the lake would be allowed to rise, but when it reached 108 the spillway would be opened, gradually at first, and at its full capacity if necessary. In this way there would be a margin of four feet for the lake to fall in dry seasons and the same amount for it to rise during wet seasons. This is believed to be ample.

The possibility of securing complete control is manifest by inspection of Plate XIX*a*,[1] which shows that had all the water entering the lake been impounded, the surface during the first twenty days of January, 1898, would have risen three inches, or, since there was no rainfall, that the run-off and seepage from the previous season were still feeding it.

From this period it would then have declined quite uniformly from loss by evaporation until the end of the dry season, May 15, when it would have stood at an elevation of 104.07 above datum, after which it bore a nearly constant relation to the accumulated rainfall and would have reached its highest level of 113.69 on January 20, 1899, a gain of 9.6 feet in about eight months had all the water been held. If, on the contrary, it had been desired to prevent any further rise at any particular stage, even the lowest, it might have been done by a spillway having a capacity of discharge indicated by the red line of the chart which represents an increment at the rate of 45,940 cubic feet per second. With this spillway capacity for this year the lake could have been held at any desired stage, or by a reduction of the discharge, it could have been allowed to fluctuate within any reasonable limits.

A spillway of 50,000 cubic feet capacity divided between the eastern and western outlets will afford ample facilities for the regulation and control of the lake and its drainage.

The relation of such a spillway capacity to the observed fluctuations during 1898 may be exhibited graphically by assuming this quantity of water to be poured into the lake basin and drawing a curve representing the rise due to this inflow, all the water being stored (see Plate XIX, Appendix III).

By taking the difference between the curve representing the lake fluctuation and the curve representing 45,940 second-feet at any date, as

[1] See Plate XIX*a* in Atlas.

for example on July 14, and plotting this difference, the result will represent the fluctuation of the lake under the physical conditions as they existed between July 14 and the end of the record. Had the sluices remained closed between January 1 and July 14 the lake would have risen to 107, and if then thrown fully open the lake would have risen only one inch higher during the entire season. Had they been entirely closed again on October 28, the lake would have gained two feet more in storage preparatory to the next dry season, which it would have entered at 108.68. By closing earlier more water could have been stored. This matter could readily be regulated by the judgment of the manager, who would doubtless have closed the valves throughout the dry season and thus have stored the entire outflow during that time.

Location of Spillways.

An important matter in connection with the regulation of the lake level is the location of the regulating works or spillway. It is seen that the lake may at times have to discharge as much as 50,000 cubic feet per second. An ideal arrangement would be to have the spillway entirely independent and separated from the canal proper or canalized river. A careful search has been made for such location on the west side between the lake and the Pacific, but no suitable place could be found that did not involve an expense almost as great as the construction of the western division of the canal itself. It has therefore been suggested that this surplus water might be discharged through the canal itself as far as Buen Retiro, and there turned into the valley of the Rio Grande, which it would be forced to follow on its way to the sea. This plan is objectionable for several reasons.

It will necessitate a widening of the canal proper from the lake to Buen Retiro, a distance of about nine miles, the most of which will be excavation in rock. This part is the Divide cut of the western division. Even if this cut be made reasonably wide, the current through it will be swift. Of course the greater the width the less the current, but it may be questioned whether a current of five feet a second in a canal 200 feet wide would be entirely satisfactory to navigation. Moreover, 200 feet width will only discharge about 35,000 cubic feet per second with a five-foot current, and there may be times when the discharge ought to run as high as 50,000 cubic feet per second. To carry this amount of water with a five-foot current would require a width of about 300 feet.

A further objection would be the difficulty of properly controlling these discharged waters after they had left the canal. The discharge of 35,000 to 50,000 cubic feet of water per second into the valley of the Rio Grande, means the creation of a torrential river ten times the magnitude of the existing river in its highest floods. This might not be an insuperable objection if the valley of the river were rock or some material not easily eroded. The soil of this valley is for the most part light, sandy and easily put in motion by swift-running water. The distance from Buen Retiro to the Pacific is about eight miles, and the river in that distance would have a fall of about 80 feet from the foot of the spillway. Moreover, the canal itself will be located in this valley, and at the gorge the width is reduced to 2000 feet. A stream like the one thus created might endanger the canal itself. The difficulties of controlling it would be great, and a large amount of the material would be scoured and carried to the ocean, perhaps to the great detriment of the

entrance to the canal. It is possible that from 10,000 to 15,000 cubic feet of water per second might be discharged through the canal on the west side and into the Rio Grande river if widened and straightened without damage, but the discharge of two or three times that amount is believed to be impracticable except at unwarranted expense.

Nor does there appear to be any absolute necessity for discharging all the surplus water of the lake on the west side. The San Juan river is to-day, and has been, its natural and only avenue of discharge. According to the estimates of the geologist and the hydrographer, its discharge in high stages has at times been as much as 50,000 cubic feet per second. The evidence appears to be conclusive that even this great discharge does not erode its banks to such a degree as to carry much sediment. The Agua Muerta below the Machuca rapids indicates that no great amount of sediment is carried in the upper San Juan, and this notwithstanding the fact that the currents have been greater than they would be under the new condition of affairs created by the canalization of the river. The fact that the small tributaries that drain into the San Juan may at times discharge as much as 50,000 cubic feet per second between the lake and the San Carlos river, is objectionable, but such discharges come at rare intervals and last but a short time. Even if the regulating works could not take care of it, the only effect would be to raise the water in the river and stop the discharge from the lake for a short period, or possibly turn the current towards the lake. If, then, the San Juan river, discharging sometimes as much as 50,000 cubic feet per second, in addition to that of its own drainage basin, as it exists to-day, with a fall from the lake to the foot of Machuca rapids of 48 feet, does not seriously erode its banks, it does not seem reasonable to expect more erosion when that fall is reduced and the discharge area of the river increased.

The Commission has, therefore, concluded that the discharge from the lake through the canal and down the Rio Grande river on the west side, should not exceed about 15,000 cubic feet per second, and that the remainder should be discharged through the San Juan river. The principal regulating works are therefore designed to be located at the site of the dam near Boca San Carlos, capable of a maximum discharge of 85,000 cubic feet per second, while the works on the west side should have a capacity of 20,000 cubic feet.

Projects and Routes.

The region within which a canal can be constructed is comprised within comparatively narrow limits. By the term "Nicaragua Route" is understood a canal route which uses Lake Nicaragua as a part of its system. For convenience this may be divided into three divisions:

First, the division between the Pacific and the lake, called the western division;

Second, the lake itself;

Third, the division between the lake and the Caribbean sea, called the eastern division.

Western Division.

Col. Childs, an eminent civil engineer, in 1850-51, surveyed and located a route for a canal over this western division. His route, starting from the Pacific ocean and going eastward, from Brito, at the mouth of the Rio Grande, followed the valley of this river to a point about eleven miles from the lake, thence across the Divide to the valley of the Lajas, which it followed to the lake. There was no harbor at Brito

and he proposed to form one by the construction of jetties and by excavating the alluvium of which the coastal plain is composed. A detailed description of the project is given in the report of the Board of 1895.

In 1873 a survey was made by Commander Lull of the U. S. Navy. He proposed to construct a harbor at Brito and to follow the route suggested by Col. Childs up the valley of the Rio Grande, but to cross the Divide farther to the north and to follow the valley of the Medio to the lake. This line was somewhat shorter than the other, but involved heavier cutting in the Divide. A full description of this route is given in Commander Lull's report.

Mr. Menocal, the Chief Engineer of the Maritime Canal Company, after further surveys, proposed to abandon the Medio route on account of the heavy cutting in the Divide and adopted practically the route suggested by Col. Childs. His first project was for a canal in excavation along the north side of the valley of the Rio Grande. Subsequently he suggested a modification of this project, which was adopted by the Maritime Canal Company, of building a dam at La Flor and creating an artificial basin 6.25 square miles in area, reaching from near the westerly side of the Divide to within four miles of the Pacific ocean. At the proposed site of the dam the valley of the Rio Grande narrows to about 2000 feet, and the surface indications of the adjacent hills seemed to promise good foundations for a dam. The construction of this dam would practically extend the lake level westward to within four miles of the Pacific ocean. From the basin thus created the Pacific ocean was reached by a canal with three locks.

The Board of 1895 suggested still another project for a canal across this western division which did not differ in location materially from that at first proposed by Col. Childs, but followed the left bank of the Rio Grande instead of the right. These several routes are shown on the map accompanying this report and a further description of them seems unnecessary, as full descriptions are to be found in the various reports and Congressional documents published by the U. S. Government from time to time.

The relative advantages and disadvantages of these several routes will now be considered, but solely on a physical basis without reference to relative cost.

The Menocal project of creating a basin in the valley of the Rio Grande by the construction of a dam at La Flor has the advantage of bringing the lake level close to the Pacific ocean. The deep part of such a basin could be more rapidly and conveniently navigated than a canal in excavation. Moreover, the flood discharges of the Tola and Rio Grande could be admitted into the basin without materially affecting the surface level, and it avoided all necessity for diverting the waters of these streams from the canal eastward of the dam.

The disadvantages of this plan are, first, the La Flor dam itself. Its crest would have to be about 120 feet above sea level, allowing 10 feet for freeboard, while the solid rock is found at about 45 feet below sea level. The total height of the dam in the deepest part would, therefore, be not less than 165 feet.

Second. If a high dam be built at La Flor to hold the level of the basin at 110 feet above sea level, all the locks will have to be placed on the west side of the Rio Grande. This is a disadvantage because the area suitable is limited.

The locks will necessarily be of high lift and located on the slope of the hills close to each other, where there is little room for additional

locks should they become necessary by future developments in the commerce through the canal. Moreover, a part of the canal itself will necessarily be built with heavy embankments or retaining walls on the slope of these hills, and the lower Rio Grande will either have to be crossed, taken into the canal, or discharged to the eastward of the proposed harbor.

Third. The creation of this basin would submerge many acres of land, not at present of great value, but which would become valuable should a canal be built.

A canal in excavation, whether it follows the right or left bank of the Rio Grande, avoids the construction of the La Flor dam, presents no special engineering difficulties, enables good sites for locks to be selected, and preserves for cultivation the fertile land bordering immediately on its banks. Of the two routes in excavation the one on the east side allows the river to discharge through its natural mouth on the west side of the proposed harbor. It is somewhat shorter than the other, but the most important advantage is that it enables the harbor at Brito to be constructed on the east side of the Rio Grande, which is considered advisable since it is contemplated to discharge a part of the water of the lake on the west side for regulation of lake level.

The Menocal project could, however, be varied by providing a lock and dam at or near Buen Retiro, and dropping down to a lower level. The basin would in this case be diminished in size, and the dam would be lowered in height by the number of feet lift in the lock. Less land would be submerged, but the basin would not be as deep nor as long. On the other hand, fewer difficulties would be encountered in constructing the locks from the La Flor dam to the Pacific, and the canal could be carried down to the sea on either side of the river with less difficulty.

The Commission is of the opinion, in view of all the circumstances, that the best location is on the left bank or east side of the Rio Grande.

Lake Division.

The lake division will be the same for any project.

Eastern Division.

The projects that have been proposed and considered for the eastern division admit of more variants than those on the western division, but all projects for the eastern division look to canalizing the San Juan river by means of locks and dams, from the lake to the vicinity of the mouth of the San Carlos river.

Three projects with their variants are all that need be considered on the eastern side.

The first is that for canalizing the San Juan river from its source at the lake to the sea. So far as the canalization of the river from the lake to Boca San Carlos is concerned, no doubt exists as to its practicability. But for that portion of the river from thence to its mouth, it is not deemed practicable, because of the difficulties of securing good foundations for dams, the torrential discharge of the San Carlos and Sarapiqui rivers and the great quantities of sand carried by them and deposited along the river channel of the lower San Juan.

A second project is that suggested by Mr. Menocal, which had for its object the extension of the lake level through the "Divide cut" to within twelve miles of Greytown. It is similar to that suggested by him for the west side. It looked to the construction of a high dam at Ochoa, a short distance below the mouth of the San Carlos river, by means of which the waters of the San Juan were to be raised to the level

of the lake. From the south end of this dam embankments were to be built in the saddles of the San Carlos ridge, to connect with the hills in Costa Rica, thus cutting off the escape of the raised waters of the San Juan on that side. In this embankment line sluices were to be built to discharge the surplus waters of the lake which find their way down to the San Juan river, as well as the floods of the San Carlos itself.

From the north end of the Ochoa dam similar embankments were to be built across the saddles in the hills on this side, until connection was made with the high ridge known as the "Divide." This was known as the San Francisco embankment line, and it crossed the rivers San Francisco, Danta and Chanchos. The number of dams, large and small, was 67, those across the rivers named being the largest. This embankment line had a length of about 15½ miles from the north end of the Ochoa dam to the Divide, of which six miles were artificial. Sluices were to be built at convenient places along this embankment to discharge the surplus waters of the drainage area to the northward.

By means of the Ochoa dam and the San Francisco and San Carlos embankments a large pool or basin of irregular shape was to be created and the surface of the water maintained at or near the level of that in the lake itself. The excavation in the upper river and in the pool was thus reduced to a minimum.

From a point near the eastern end of the Ochoa dam the canal was carried in excavation to the valley of the Danta, or Florida lagoon, and from thence in pools and cuts to the valley of the Limpio which it followed to the Divide cut. This cut is about three miles long and has an average depth of 134.4 feet, the maximum depth being about 350 feet. After crossing the Divide the canal descends, by means of three locks of high lift, into the valley of the Deseado which it follows to the coastal plain, after reaching which it continues in a nearly direct line to Greytown.

A third project is to construct a dam in the San Juan river just above the mouth of the San Carlos, giving slack water navigation from the lake to the dam, and thence by a canal in excavation along the left bank of the San Juan or near it, to the junction of the San Juan with the San Juanillo, and from thence across the coastal plain to Greytown.

Each of the two latter projects admits of variants. The Menocal project can be varied by locating the dam across the San Juan above the mouth of the San Carlos river, starting with excavation to the eastward of that dam and thence following a route substantially as projected by Mr. Menocal himself. Or, a lock may be used in connection with this dam and the height of the embankments be correspondingly reduced. This would increase the depth of the Divide cut by the same amount. The practicability of a dam only a short distance above the mouth of the San Carlos river has heretofore been doubted, but the surveys show that such a dam is not only practicable but will be easier of construction than one at Ochoa.

Another variant would be to build a dam near the lower Machuca rapids and lock down 24 to 30 feet, then follow the rest of the route practically as laid down by Mr. Menocal, the object of the latter variant being to avoid the construction of a high dam at Ochoa and to reduce the height of the San Francisco and San Carlos embankment lines. This would increase the depth of the Divide cut.

Another variant would be to construct a dam at Tambor Grande and an embankment on the

south side connecting with the hills in Costa Rica. This would take the place of the Ochoa dam and eliminate the San Francisco and San Carlos embankments. This is regarded as impracticable.

Other variants, such as increasing the number of locks or varying their location, suggest themselves.

The third project can be varied by constructing one or more dams with locks in the upper river, thus reducing the height of the dam at San Carlos. Or, after reaching the junction of the San Juan with the San Juanillo any one of several routes may be taken to the sea.

Mr. Menocal's project has an advantage in that it is two miles shorter than the other project following the bank of the river.[1]

Its disadvantages are, first, the engineering difficulties encountered in building the Ochoa dam. This dam being located but a short distance below the mouth of the San Carlos river, its construction would be attended with no little risk.

Second, the San Francisco embankment line is another troublesome engineering construction. This embankment follows an irregular line from Ochoa to the Divide. No less than 67 dams will be required, some of them insignificant in size, but four of them of great length and of more than ordinary difficulty to build and maintain, because of their great height and the pressure of water to which they would be subjected, as well as to the fact that the soil on which they would have to be founded is overlain for a great depth with soft ooze.

A third disadvantage is the Divide cut itself. This, as before stated, is over three miles long. In addition, it is curved, the curvature being in places the maximum that should be allowed in a canal of this magnitude. This would render navigation difficult. Its great depth would also be a constant menace, for while it is believed that the rock for the most part would stand, there is some likely to cause trouble. A large portion of it, dacite, a rock that weathers rapidly, is of light specific gravity, and not to be trusted in a deep cut like that through the Divide. Again, on account of its depth and length it would necessarily be made of the minimum width practicable for navigation; consequently if the canal were working to its full capacity there would inevitably be some delay to vessels passing through it, since two large ships could not pass each other. Vessels would therefore accumulate at either end to be passed at stated intervals in fleets.

The variant providing for the construction of a lock and dam at Machuca, locking down say 24 feet, would reduce the height of the San Francisco embankments and the Ochoa dam; but the excavation in the San Juan river and eastward to the eastern end of the Divide cut would be increased by this extra depth. There would still be the Ochoa dam, though of less height, to be constructed in contention with the floods of the combined San Juan and San Carlos rivers. If the dam be built above the mouth of the San Carlos river instead of below it at Ochoa, there would yet remain the objectionable San Francisco embankments and the Divide cut.

The project which looks to the construction of a dam above the mouth of the San Carlos river, and follows close to the north bank of the San Juan river as far as the junction of the San Juan and San Juanillo, has the disadvantage of an increase in length of about two miles,[1] but on the other hand it is believed the difficulties of

[1] Comparison of distances between the lake and Greytown harbor.

construction will be lessened because of the reduction in the height of the embankments and by avoiding the Divide cut.

There are, nevertheless, several hills of considerable height to be cut through on this route. The Tamborcito hill will require a maximum depth of 230 feet of cutting in rock, but it is less than a half mile in length, and the material will be required on the work, while an attempt to circumvent the hills may involve an embankment founded upon a depth of 80 feet or more of black sand in the bed of the river. From this point to Lock No. 1 most of the canal trunk will be enclosed between embankments built of the silt from the excavations. In short distances they may exceed 30 feet in height, with a pressure of twenty feet of water.

A variant on this project will be in the construction of two dams in the river above the one near the mouth of the San Carlos. But it has no advantage over the other except that it enables the lower dam to be reduced in height. This is not considered of great importance, for while the construction would be easier, the main difficulty would be in the foundations and they would not be materially different. It has several serious disadvantages, however, in obstructing the passage of large volumes of water at narrow sections of the river and in confining the navigation below the upper dam to a narrow channel excavated in large part through rock.

Numerous other adjustments in detail may be made, both in the alignment and grade, but they are not of sufficient importance to warrant consideration prior to final location.

Greytown Harbor.

A suitable harbor with a safe entrance, at the eastern end of the canal, is an essential requisite to its proper operation. No such harbor now exists. About fifty years ago there was a good harbor at Greytown with thirty feet of water in the anchorage and at the entrance. The sand, however, that has been brought down by the San Juan river and deposited in the sea has closed the entrance, and in a large measure filled up the harbor itself. This sand movement has been going on for ages, as the numerous lagoons that have been formed parallel to the coast line testify. The sand has been ejected from volcanoes in the region of the headwaters of the Costa Rican tributaries of the San Juan, carried down to the sea by the river, deposited on the ocean bed, and then transported by wave action in one direction or the other according to the prevailing winds and the resulting direction of the waves.

By the term "harbor" it is not intended to convey the idea that a large harbor should be constructed for commercial purposes. A harbor of sufficient area to accommodate the vessels that arrive for the purpose of passing through the canal is all that is considered necessary. It is not expected that vessels will lie in such a harbor for any length of time, but will move through, either in one direction or the other.

For canal construction purposes a harbor is necessary. One of the first things, therefore, to be done in undertaking the construction of the canal will be to form a harbor of reasonable depth. This has an important bearing in estimating the cost of construction.

The San Juan river drains a basin of about 17,000 square miles. The silt deposited in its delta during past ages has built out the coast, with characteristic lagoons and extensive marshes covering the broad plain between the present shore line and the original foot-hills of the Cordilleras.

The delta may be said to begin at a point

twelve miles in an air-line from the outer coast, where the San Juanillo leaves the main trunk. This stream has been turned parallel to the coast, and finally reunites, through a series of lagoons, with the lower San Juan. The latter is flanked by lagoons indicative of original beaches, the three to the north being typical of the prevailing direction of the drift on this portion of the coast, due to the angle of wave incidence. These lagoons are nearly parallel to the existing coast line and are separated by strips of land enclosing long, narrow lakes. The date of these formations is not ascertainable from any existing records.

It would seem that what is now the lower San Juan river was at one time the main stream and discharged most of the sediment, the waves produced by the trade winds carrying a part of the material to the westward and a part of it to the southward, the westerly movement of this sand having formed lagoons whose longer axes are nearly parallel to the coast. The prevailing winds are from the northeastward and while they rarely blow with great violence, they blow steadily and with considerable force, creating a sea which stirs up the light sand of which the beach is composed and carries it along in great volume. One has only to observe the waves charged with black sand, running diagonally along the beach, to realize their potent agency in transporting this material.

The Board of 1895 gives a very complete description of the sand movement on this coast, a full discussion showing how the destruction of Greytown harbor as it formerly existed was brought about, and the steps necessary to be taken in the construction of a new harbor. The conclusions arrived at by that Board were that the Maritime Canal Company's proposed entrance is inadmissible, and the Harbor Head entrance inexpedient, and that the best results will be obtained by locating the entrance approximately half-way between the two. This Commission is of opinion that equally good results, at less cost, can be obtained by a change in the entrance and form of the harbor itself. The Commission has, therefore, located the east jetty about 2000 feet westward of the position suggested by the Board of 1895, the harbor itself to be about 5000 feet long by 1000 feet wide, and the entrance between the jetties to be 600 feet.

The construction of a jetty across the path of moving sand must of necessity cause accumulations of drift to windward, hence the angle formed between any such projecting structure and the shore must gradually fill up and the shore line advance seaward until the capacity of this receptacle is exhausted. This advance diminishes as the depth and consequent capacity of the pocket increase, but it shows that some expense must be incurred for the maintenance of the harbor either by jetty extension or by the removal of the material from time to time, which would otherwise find its way around the end of the jetty and into the channel. A study has therefore been made of the various surveys of the harbor with a view to determining the probable amount of material to be controlled in the maintenance of the entrance. This amount is estimated to vary from 500,000 to 730,000 cubic yards annually.

The entrance to the harbor will be formed by two parallel jetties about 600 feet apart, the easterly one about 2670 feet in length, the westerly one 2500 feet. They will extend seaward in a northerly direction, thus giving shelter from the sea, which comes generally from the northeastward. As the sea strikes the shore line with considerable violence at times, these

jetties will be constructed chiefly of heavy stones not easily moved by the force of the waves. To obtain suitable stone for this purpose in large quantities and with the utmost dispatch, so that a part at least of the jetty can be quickly constructed, quarries will have to be opened at the most favorable locations.

Brito Harbor.

At the westerly terminus of the canal there is no harbor. The nearest harbor is that at San Juan del Sur, about eight miles to the southeastward, but this cannot be put to any useful purpose so far as the canal itself is concerned, though it may be utilized in a measure during the early stages of canal construction. A harbor will have to be constructed at Brito as at Greytown. San Juan del Sur could only be used to advantage during construction by the building of a railroad from there to the canal.

The remarks as to the capacity of a harbor at Greytown will apply with equal force to Brito. In other words, a harbor of refuge is not needed, but only such a harbor as will make the canal available for commerce. Vessels will seldom go to Brito unless entering or leaving the canal.

The conditions on this coast are not as forbidding as they are on the eastern. The sand movement is slight and the winds are mostly off shore, consequently the difficulties to be encountered will be more easily overcome. The mean rise and fall of tide is about 7 feet. The sea during the greater part of the year breaks normal to the direction of the shore; the prevailing wind is from the northeast, and while west and south winds sometimes blow they are of rare occurrence.

The shore is bold, and deep soundings are found at no great distance from it. The shore line trends from northwest to southeast, but the rocky promontory on the north side of the Rio Grande projects into the sea and gives a certain amount of protection.

On account of the rapid increase in depth from shore seaward, an outer harbor is almost impracticable within the limits of reasonable cost, so that one is restricted to the formation of an inland harbor within the area that is now occupied by a swamp. From borings made and all information obtainable it is believed that this material is easy to excavate. In fact it is known that some of the borings taken by the Canal Company in close proximity to the proposed harbor, which seemed to indicate rock at no great depth, were deceptive and that the boring apparatus struck boulders which were supposed to be solid rock.

The harbor proposed by Col. Childs opened directly to the south, and was protected by two jetties, one springing from the sandy beach and running southward, the other, but smaller jetty, springing from the Brito promontory and running southeastward. The entrance was 400 feet wide. An inner harbor was formed by a change in direction of the entrance at nearly a right angle, which gave good protection. The size and depth of the harbor proposed would be utterly inadequate to the present size and draft of ships. A diversion of the Rio Grande to the eastward of the entrance was a necessary feature of this scheme.

Capt. Lull, in his project for a harbor, made some changes in the Childs project, with a view to giving a wider entrance and more capacious and deeper harbor, suited to the increased depth which he proposed.

The Maritime Canal Company also proposed a plan for a harbor, increasing the area to 103 acres.

The Board of 1895 suggested still another

project, the main feature of which was the extension of the west jetty of the Lull plan to a length of 3600 feet. This was, however, only provisional, with a view to an approximate estimate and not as a definite project necessarily to be followed. That Board distinctly stated that "the information available is not sufficient to enable final plans and estimates to be made."

All the plans proposed have certain inherent defects, and it is scarcely possible to construct a harbor at this place that will be perfect. A breakwater to shelter an entrance becomes a very expensive structure in such a place as Brito and is liable to introduce other objectionable features.

It is believed, however, that the difficulties of a vessel's entering between two jetties that project seaward in the direction of the advancing waves have been overestimated in the case under consideration. San Juan del Sur is a fairly good harbor, yet its entrance is open to the sea. It is said that no trouble is experienced by shipping at this place from such exposure. A Pacific Mail steamer calls at this harbor once a week throughout the year. She does not go to a dock, for there is none at which she could lie, but it is understood no trouble is experienced in lightering from her anchorage.

To permit a vessel to enter the harbor normal to the swell, and at the same time to guard it against agitation from the admission of large waves, are conditions not easily satisfied, but the Commission believes that the form of harbor presented with this report will meet the conditions as nearly as it is practicable to do within the limits of reasonable cost and in a manner less objectionable than any other yet proposed.

The plan is to build a jetty from a point on the beach about 3600 feet east of the Brito promontory, extending out into the sea in a direction nearly south-southwest to the seven-fathom curve; then excavate a harbor of the form shown on the plan, to the eastward of a north and south line through the root of the jetty, the entrance to be 600 feet wide at the throat. This will give security and comparatively still water in all winds except those coming from south by west and a few degrees either side. The promontory will protect from winds coming from a more westerly direction and the jetty from all winds coming from a direction east of south. The basin to be excavated has a bottom area of about 135 acres and a depth of 30 feet at mean low tide with a depth of 36 at the entrance. As the movement of sand is slight the cost of maintenance will not be great.

The Rio Grande in this project will not be diverted at its lower end, but it will have to be enlarged in cross section in order to carry increased discharge.

If the conclusions reached by this Commission that this harbor gives all the protection that is needed, be found by time and experience to be incorrect, a jetty from the promontory eastward can be added at any future time. It is believed, however, that such jetty will never be required, and no provision has been made in the estimate for one.

Dams and Embankments.

To construct safe, durable and stable structures for the control of the drainage and for navigation is a *sine qua non*.

The principal causes for the failures of dams or reservoirs may be traced to defective foundations, improper design or imperfect construction, single or combined. Probably the most frequent causes of their failure are, their permeability causing a breach by seepage, and their lack of spillway capacity allowing the dams to be overtopped by floods.

The sites proposed in Nicaragua for the dams are such that, in connection with the large impounding capacity of the lake acting as a reservoir, there is little or no danger of sudden floods reaching their crests, so that the risk from this source is believed to be eliminated by providing an ample waste-way and freeboard. This remark applies with still greater force to the embankment lines, which may be used for the purpose of enclosing large artificial lakes in basins of limited drainage area and not subject to the discharge from the river.

Moreover, there is an abundance of material suitable for puddle, which if properly applied will secure impermeability. The main difficulty, therefore, is that resulting from insecure foundations. For the dams in the rivers closing the summit level, satisfactory rock bottoms and abutments are available, but to reach rock on the San Francisco embankment line is a more difficult and expensive problem.

Dams on the Eastern Division.

In view of the large amount of earth and rock excavation and the necessity for disposing of the spoils, it was decided by the Maritime Canal Company to construct high rock-fill dams on both sides of the lake for the purpose of impounding the waters of the summit level, but the desirability of avoiding the San Carlos river and of facilitating the construction of the dam itself, has led this Commission to select a new and better site a short distance above the mouth of the San Carlos river.

The borings made on the site of the proposed Ochoa dam revealed rock at 17 feet below sea level, suitable for foundations. The width between banks is relatively narrow, for at an elevation of 100 feet above sea level it is about 1400 feet. As this site is below the junction of the San Carlos river, which at flood stages, it is estimated, may discharge 100,000 cubic feet per second in addition to the lake and San Juan river drainage, this large volume must either be disposed of over spillways on the San Carlos ridge or be allowed to waste over the dam itself. Its sediment also would be deposited in the bed of the stream above the dam and cause constant shoaling. At lower Ochoa the sand extends to 30 feet below sea level. To avoid these serious objections as well as to eliminate, if possible, the embankments of the San Francisco and Florida lagoons, examinations were made for a dam site at Tambor Grande island. The subsequent borings in the bed of the river at this site, however, showed an erosion of the bed rock extending to 128 feet below sea level, which would necessitate a dam in this narrow gorge of the river nearly 250 feet in height, subject to the flow of the entire drainage basin. This project was, therefore, discarded.

The more recent examinations and surveys, made on the wider reach of the river above the San Carlos, gave results which were quite satisfactory. Here the flowage line is almost continuous, requiring but one small embankment, while the section affords ample weir length. Good solid rock foundations exist at about 15 feet below sea level. Thus the maximum height of the dam from the bottom of the foundation would be 138 feet. The construction of a dam at this point avoids the serious objections to the Ochoa site, and also reduces the cost and difficulties of construction.

The estimates are based upon concrete, which can be mixed on the site. Regulating works and sluices can be provided in the original river channel, and the entire length of the crest may be utilized for a spillway in case of necessity.

The typical section on which the estimates are based is the ogee rising from the natural bed of the stream at an elevation of about 38 feet above sea level to the proposed weir sill at 98, with regulating sluices to control the higher stages. The width of the base at the deepest point is 100 feet. The ordinary stage of water at the foot of the dam is about 55 above sea level, while extreme low water is about 45.

Sites for Low Dams.

There are various locations on the river where dams may safely be placed for variations of project. Taking these in order, coming down stream, the first may be at *Castillo* where the river flows over ledges of basalt which is somewhat jointed, giving it the appearance of being stratified, but it is believed to be firm and strong. The anchorages also are good.

At *Upper Machuca*, three miles above Machuca, the rock is calcareous sandstone with limited weathering. Solid rock is usually found under a few feet of sand in the river channel, but the rock in the adjacent hills is weathered down nearly to the same level as the surface of the solid rock in the channel so that the anchorage must be in residual clay and soft rock.

The *Machuca site* is situated across the head of Campaña island. It is based on a fine-grained light-bluish gray rock, evenly bedded, and closely resembling a fine-grained quartzite. The borings on the south banks, however, show great depths of weathering, making it desirable to shift the location farther up or down stream.

Conchuda about two miles above the Boca San Carlos also affords a possible dam site and has been considered with a view to reduce the large amount of rock excavation incidental to the Machuca dam projects.

Relative Cost of the Several Concrete Dam Projects Between the Lake and Boca San Carlos, Including the Latter.

These estimates are based upon the same prices in each case and are submitted merely as a guide to the relative merits of the plans:

Low dam at Upper Machuca	$1,045,569
Low dam at Lower Machuca	866,040
Low dam at Boca San Carlos	2,633,124
	$4,544,733

Low dam at Lower Machuca	$1,240,785
Low dam at Conchuda	2,721,411
Low dam at Boca San Carlos	2,633,124
	$6,595,320

Both of the above schemes would require in addition a large amount of rock excavation in the river to create navigable channels in the pools, which would be avoided by the higher single dam.

High dam at Boca San Carlos, of concrete, $4,570,340.

San Carlos and San Francisco Embankment Lines.

The hills to the southeast of the San Carlos river contain depressions which would have to be closed by earthen embankments to provide for the Menocal project, with weirs through the saddles. The depth to hard rock varies from probably 60 to 100 feet, but as the San Carlos embankments will be avoided by the change of the dam site to a point above the Boca San Carlos, no further discussion of its embankment line is required. It would be necessary, however, to extend the San Francisco embankment line from Ochoa up the left bank of the river to connect with this new location, involving heavy work.

Embankment Foundations.

To ascertain the character of the material underlying the proposed embankments crossing the Florida, San Francisco, Nicholson and Chanchos depressions, deep borings were made in each which revealed the residual clay and soft rock beneath the alluvium but in thinner strata than on the hills.

"The rock is only moderately hard, consisting chiefly of talcose volcanic tuff with a thin bed of earthy limestone." The silt in these depressions and swamps apparently extends to about ten feet below sea level and renders it desirable to reduce the height of the embankments as much as possible. All the routes traverse the reach on the left bank of the San Juan from Boca San Carlos to the San Francisco near its mouth and hence cross these lateral tributaries, but at different elevations dependent upon the number and location of the locks.

Dams on the Western Division.

The La Flor Site.

Much has been said pro and con concerning the possibility of constructing a dam at this site, and the Board of 1895, basing its conclusions upon certain exhibits as to geological structure, declared it inexpedient, in view of the slight advantages and the ability to construct a canalized channel at a somewhat greater cost on the left bank of the Rio Grande.

In the light of more recent borings and their interpretation by Dr. Hayes, this Commission is of opinion that a dam at this point is practicable.

Buen Retiro.

The summit level would terminate at Buen Retiro, about 9 miles from the lake, where the topography is well adapted for the purpose, as it affords opportunities for spillways directly into the bed of the Rio Grande and Guachipilin, and for a good lock site. Here a small ovoidal hill rises from the bottom of the valley "composed of a calcareous shale more or less disintegrated, but sufficiently firm for foundation purposes." The rock is about 50 feet above sea level, and comparatively little silt would have to be excavated to place the foundations. The regulating works with the lock will close the summit level, making it unnecessary to build a dam at this site.

No other dams are required on the west side under any of the variants.

Canal Locks.

On the route selected as a basis for the estimate it is proposed to construct 6 locks of 18.41 feet lift each on the eastern division, giving a total of 110.46 feet, and four locks of 29 feet lift each on the western division, giving a total of 116 feet, the difference of 5.54 feet being due to the difference in rise of tides in the two oceans.

In estimating the cost of the locks the large Poe lock at the Sault Ste. Marie canal at the outlet of Lake Superior was taken as a standard, and the dimensions of lock chamber, fore- and tail-bays, gates, culverts, etc., were modified to adapt them to the present requirements. The lock pits were extended to 15 feet below the floor to provide for the culverts and valves and the necessary foundations. The following are the dimensions used for one of the 18.41 feet lift locks:

Number of culverts	4	
Length of floor and side walls	939.5	ft.
Width of floor in the clear	80.	"
Height of side walls = lift + draft + 4 ft.	52.41	"
Length of sides between abutments	601.75	"
Width of side walls at top	10.	"
Width of side walls at bottom	21.53	"
Width of abutment walls at quoins	31.77	"

On the western division the topography is such that the best results are obtained by the use of four locks having the same dimensions as to length and breadth, the only modification being in the lift and thickness of the walls and foundations.

Upon this basis the 6 locks on the eastern division will cost	$9,560,400
The 4 locks on the western division will cost	7,412,580
Making the total cost	$16,972,980

Quantities.

The general advantages and disadvantages of the several locations have already been stated under the head of "Projects and Routes," but no final location nor estimate could be completed until after the quantities of the different classes of material on the several routes had been determined.

As a large number of variants are possible, particularly on that part of the route lying between Boca San Carlos and the sea, and as it was impossible to determine before the preliminary surveys were completed and plotted which would give promise of the best results, the detailed geological examination by borings on any specific route had to be deferred for a later date. The classification which has been made along these low level routes is therefore based upon outcrops, borings by the Canal Company confirmed by the Commission at a few points, and an examination of the region, which is believed to be ample for the purpose of an estimate.

The collection, plotting and computing of these data have required considerable time, but so far as quantities are concerned they are quite reliable. There may be variations in the classification where the lines of separation between different materials merge into one another, but they will be more or less equalized, so that errors due to this cause will be small.

For more convenient reference and comparison of the quantities under the variations of line and grade, they have been arranged in a table[1] which gives the amount of excavation and embankment in each division and for each project and class of material, excepting for the harbors, railroad and dams. The cost of the dams, locks, weirs, and other structures is given in the item entitled "Auxiliary Cost," appended to each division.

By the aid of this tabular statement of quantities an estimate of the cost of constructing the canal trunk may readily be obtained by applying any suitable unit price to the factors as stated. The amount of dredging for the two harbors, not included in the table, which should be added to the totals, is, for Greytown, 10,748,900 cubic yards, and for Brito, 9,500,000 cubic yards. The jetty and other harbor work is not included in the table, but is stated in the estimates.

For the route recommended by the Commission, passing to the north side of Silico lake, following the left bank of the San Juan and Rio Grande rivers, and having a bottom width of 150 feet, with 10 locks and one dam, the quantities from ocean to ocean, exclusive of the railroad, are:

	Cu. yds.
Dredging, river and coastal plain	61,738,842
Dredging, lake and harbors	37,557,750
Earth excavation and embankment	29,907,996
Disintegrated rock	15,248,312
Solid rock	7,573,992
Rock under water	754,378
	152,781,270

[1] See "Table of Quantities" in Atlas.

Unit Prices.

The Commission has endeavored to reach conclusions in respect to the probable cost of the canal that will be fair and just. It has tried to have the figures represent the probable cost of the canal as nearly as can be ascertained, without being too high or too low. It must be admitted, however, that any estimate of probable cost is to some extent a matter of judgment. It is not possible to determine this matter with absolute certainty, as many of the elements on which one's judgment would be based are not accurately known. One's experience in like work, and the experience of others, are the only guides. There has never yet been a work of similar character executed under exactly similar conditions, and it should be remembered that work on a small scale, or which is greatly distributed and not *en masse*, involves more loss of time and labor and is consequently more expensive. The work on the Panama canal would perhaps come near it in some respects, but no one would think of comparing the extravagant methods which characterized the early history of that enterprise with the methods that should be employed on this.

The latest work of magnitude of this character which affords to some degree a means of comparison is the Chicago drainage canal. The total excavation for this work amounted to about 12,318,000 cubic yards of rock and 26,087,000 cubic yards of earth, a total of 38,405,000 cubic yards, of which about 10 per cent. was dredging. The earth was of every variety from soft mud to hard indurated clay with boulders; all being included under the name of "glacial drift." The rock was the Joliet limestone, stratified in nearly horizontal layers, and is described as ideal for ease in excavation. The proportion of rock to earth is less in Nicaragua than in the Chicago drainage canal. The actual average price paid for excavating "glacial drift" at Chicago was 29 cents per cubic yard. The average cost of rock was 77 cents. If the Nicaragua canal were located near Chicago and its rock and earth similar in character to those of the Chicago drainage canal, it is probable that the average cost for earth excavation would be the same in each. The earth in the Nicaragua canal varies in character from stiff, indurated clay to diluted silt. The range is equally wide in the Chicago drainage canal. It cannot be asserted that the earth is alike in the two places, but it is believed that it may be substantially so. Under such circumstances it might be fairly assumed that the average cost of earth excavation, if the canal were located near Chicago, would be 29 cents.

As the Chicago drainage canal affords the nearest precedent available and as the actual average prices of that work have been taken as a basis, it is necessary to state the classification of the material as specified for that work, which was as follows:

"For the purpose of letting the contracts the material to be excavated was divided into two classes, rock and 'glacial drift.' The first term explains itself, but the character of the material termed 'glacial drift,' this being an entirely arbitrary classification, needs some further explanation. As defined in the specifications, 'glacial drift shall comprise the top soil, earth, muck, sand, gravel, clay, hardpan, boulders, fragmentary rock displaced from its original bed, and any other material that overlies bed rock.' In fact, all these materials are found in all degrees of intermixture, from soft black muck, which can be pumped with centrifugal pumps, to a conglomerate of sand, gravel, clay, and boulders cemented together with almost the hardness of rock, and only to be excavated by means of the

strongest steam shovels, and sometimes even requiring blasting to break it up."

In Nicaragua the rock on the western division is chiefly a calcareous shale, thinly stratified and much broken. Some pits of considerable depth have been excavated without blasting, and the rock has been used for macadamizing the roads. It is believed that a large part of this rock could be excavated with steam shovels without blasting. It is drilled slightly easier than the Chicago limestone, and is more brittle. The location of the spoil banks would be quite similar to that of the Chicago work. It is therefore probable that some of this rock could be excavated for a price slightly cheaper than the Chicago rock. Some of it, however, it is known, will cost more. It is probable that, taken as a whole, it could be done for the same price, and it is so assumed.

Between Lake Nicaragua and the Caribbean sea, viz., the eastern division, the rock is basalt, dacite, sandstone and volcanic tuff. The basalt and dacite are both considerably harder to drill and blast than the Chicago limestone. In the larger cuts the waste material will have to be transported some distance to the dumping grounds. For these reasons it is estimated that the cost per yard will be increased 10 cents. Therefore it is assumed that if the Nicaragua canal were located near Chicago, the cost of excavating its rock would be 87 cents per cubic yard on the eastern division and 77 cents per cubic yard on the western division.

With reference to the actual cost of work at Chicago Mr. Isham Randolph, the present Chief Engineer of that work, writes as follows:

"The prices on our work ranged from 59 cents to 80 cents for solid rock and from 19.9 cents to 56 cents per cubic yard for glacial drift. This glacial drift, however, covered material which under railroad specifications would come under the heads of loose rock and hardpan. The average price paid on this work per cubic yard was for solid rock 77.3 cents, for glacial drift 28.7 cents." . . . . .

"In the light of our experience I believe that a work of like magnitude prosecuted under similar conditions could be put under contract at a reduction of about 15 per cent. from our ruling prices; in other words, that rock work should be done for 65 cents and earth for 24½ to 25 cents, which prices would, I believe, provide a fair margin of profit for the contractor."

Mr. Lyman S. Cooley, former Chief Engineer and Director of this work also concurs in this opinion, stating that some very hard glacial drift was removed for 26 cents per cubic yard and that the actual cost of rock work was about as follows:

	Per cu. yd.
For plant	15 cts.
" loading	15 "
" hoisting	15 "
" channeling	5 "
" drilling	6 "
" explosives	8 "
Total	64 "

including contractors' profits.

It yet remains to assign the relative cost of work in the United States and in Central America. This will involve greater uncertainty, for the reason that there have been no large works in Central America with which comparison could be made. There has, however, been some railroad building in all of the Central American States, often in amount sufficiently large to require the importation of labor, thus making the conditions of labor similar to those which would obtain if the Nicaragua canal should be built.

Mr. Wm. H. Keith, Contractor, reports the cost of work on the National Railway of Costa Rica to be for solid rock 60 cents in gold per cubic yard, for loose rock 30 cents in gold per cubic yard, and dry earth 18 cents in gold per cubic yard, concrete in place, including "forms," $9.00 per cubic yard.

Mr. Louis Wichmann, General Manager of the Atlas Company, who has been engaged in building a railroad, six miles and a half in length and 2½ feet gage, from Greytown to the lower San Juan river, states "that the total cost per cubic yard of excavation on the Silico Railroad is $1.25 Nicaraguan currency, equal to 50 cents gold."

In explanation of this abnormally high price, he says that "the disadvantages were extremely bad weather, especially in June and July, during which time we had some seven weeks of continuous rain, and the principal part of the material being heavy clay, it was very difficult to handle."

"Being entirely without mechanical appliances, I had to rely on manual labor, which, considering the nature of the soil and constant downpour of rain, has proved a great drawback."

"The material on the first big through cut at the Silico end consisted of conglomerate with large round boulders, which could only be removed after blasting, and unfortunately, owing to the American-Spanish war, we were unable to secure explosives at the time when they were most needed."

Other difficulties mentioned were the long carriage to the spoil banks and the fact that all supplies, tools and provisions had to be transported on the backs of the laborers.

These conditions and prices cannot therefore be cited as being comparable to the probable cost of so great a work as the construction of this canal, where the most modern appliances should be used.

Quite recently it is credibly stated that the Silico railroad had cost more than was anticipated, and that the total cost was from $110,000 to $120,000, length 6½ miles, equivalent to $16,923 to $18,461 per mile, and that this cost included everything—road-bed, rails, rolling stock, bodegas, wharves, and all terminal facilities at both ends. It was built in very bad weather and under great difficulties. The rolling stock consists of one locomotive, eight freight cars, two construction cars and two passenger cars, which were imported. The ties on this road were furnished and put in place for about 24 cents apiece in gold.

"The cost of excavation varied from 50 cents to $1.00 (Nicaraguan currency) per cubic yard, depending upon the condition of the weather and the labor. During the early part of the construction, Fortune island negroes were employed, but were found unsuitable for the work. While these men were employed, the cost of excavation was rather high. The labor now consists of natives and Jamaicans, and the cost of excavation is kept below 70 cents.

"The cost of food for each man per day varied from 52 cents to 75 cents. This is included in the cost of excavation. The material chiefly excavated was blue and brown clay. In handling the blue clay, the rains had no effect upon it whatever. The brown clay becomes rather difficult to shovel when wet, as it has a tendency to stick. In the former, the same amount of material can be hauled on a wet day as on a dry day. The haul in some cases was over four hundred feet. During rainy days the work was not interrupted.

"The rate of exchange at present is 200 per cent. premium."

An engineer of large experience in Guatemala states that prices for grading on railroad work in that country were as follows: for earth, from 30 to 40 cents; for loose rock, from 65 to 85 cents, and for solid rock, from $1.40 to $1.75, exclusive of cost of administration and engineering. The prices paid for clearing ranged from $65 per acre on the swamp work, to as low as $25 for the upper end of the line. The cost of masonry, where the haul was less than half a mile, was about $24 to $28 for first-class, $14 to $18 for second, and $10 to $12 for third. "In all of the foregoing, prices are expressed in the silver of the country." The rate of exchange is not stated.

Another engineer, also in Guatemala, states that the unit prices there were, for earth 40 cents, telpetate $1.00, loose rock $1.25, solid rock $1.80, masonry exclusive of cement, third class $10, second class $16 and first class $25 per cubic yard. "These prices include a good profit if work is properly handled." They are all on a silver basis. Converted into gold at the Nicaragua ratio they would be: for earth, 16 cents; telpetate, 40 cents; loose rock, 50 cents; solid rock, 72 cents; third-class masonry, $4.00; second-class, $6.40; first-class, $10.00.

Mr. M. P. Carter, Civil Engineer on the construction of the Cauca Railroad in Colombia, where the rainfall is said to exceed 300 inches a year, testified under oath that "a man working in earth work would move three or four yards a day at 40 cents a yard, that is the average. For loose rock, that has been loosened a little with a pick, he might move a yard and a half or two yards a day at 80 cents a yard, and for conglomerate, a man would not move more than two-thirds or three-quarters of a yard per day at $2.20 per yard." All of the above prices are in Colombian money, which would make the equivalents in gold for earth, 17.2 cents, for loose rock, 34.4 cents; for conglomerate, 92 cents.

(Extract from a letter from Mr. Harold R. Miller, dated Atlas Line of Mail Steamers, New York, April 22, 1899.)

"The three rates for earthwork and conglomerate were 40 cents, 80 cents, and $2.20, Colombian, as per Mr. Carter's evidence. The exchange at that time was 130-150, say 140 per cent.; that makes 17 cents, 34 cents, and 92 cents, gold. To-day the exchange is 230 per cent., viz: $1 gold is $3.30 Colombian. Labor, of course, has not risen in proportion with the exchange, so that construction work is really cheaper to-day than then, because contractors get more currency for their gold and pay about the same rates. Labor is about $1 Colombian in the interior, $1.40 to $1.60 on the coast. The conditions on the isthmus are different from the rest of the Republic, owing to the silver currency, which alone prevails on the isthmus; the rest of the Republic uses paper, which has about 20 per cent. discount as compared with silver."

(Extract from communication, dated October 30, 1897, from Edwin F. Smith, Civil and Hydraulic Engineer.)

"In conclusion, I desire to say that, . . processes of dredging have improved very much in recent years, and large companies in the United States would, I think, be found willing to take such contracts at Greytown, and on the line of the Nicaragua canal at less than the figures given in the estimates of the Canal Company.

"This is true not only of dredging, but also of rock excavation. There are construction companies and contractors handling material on the Chicago drainage canal with modern appliances, who would, no doubt, eagerly compete for such contracts as those of the rock cut through the Eastern Divide and the building of the Ochoa

dam, and the dredging of Greytown harbor and the canal through the lagoons."

(Extract from a communication from Col. T. P. Roberts, Chief Engineer Monongahela Improvement.)

"On the Nicaragua canal, if extra good prices are paid foremen and bosses, the actual cost of work will not be much in excess of that for which it could be done here. A general increase of 25 per cent. over American prices ought to be sufficient. While I would thus suggest a reasonable unit price for items of labor, I would advise a liberal percentage on the whole work, to cover engineering and management. Administration expenses will doubtless be very high at first, but this item will diminish after the officials have become acclimatized. Physicians and sanitary engineers should be employed to select the places for camps, provide the water supply, and look after the drainage. If this be properly done, the cost for hospital service would not be great. I do not see why this item should be differentiated. . . . . A millage tax on all salaries and wages should be fixed to maintain hospitals.

"It has been my observation for several years past that American engineers have been overestimating the cost of work. They appear to me to not fully realize the wonderful improvements which have been made in this country. Many of them still think that French and German methods on canal work admit of little improvement, but such engineers have not been attentive students of the Chicago drainage canal experience.

"In July of this year, six locks and dams were let on the Monongahela river. The United States Engineers' estimate for them all was about $1,200,000, which amount I thought was about the right thing, but, although the estimate was publicly known, a number of responsible contractors bid less than $800,000, and it was actually awarded for less than $700,000. The bidder failing to secure bondsmen, the Department ordered another letting."

For convenience of comparison these prices are tabulated as follows:

	Earth.		Solid rock.
Chicago basis	29		77
	Earth.	Loose rock.	Solid rock.
Costa Rica	18	30	60
Guatemala	14	30	63
"	16	50	72
Colombia	17	34	92
Average	16¼	36	71¾

From this it appears that the actual cost of earth work in these tropical countries is in general less than that given for the Chicago basis. The average for earth and loose rock is 26 cents, which is less than the Chicago price of 29. The average of the rock work is also five cents below that at Chicago, so that it would seem that the statement of Mr. Shunk, Chief Engineer of the Intercontinental R. R. Commission, is apparently correct that "an estimate of like work at home would be fairly applicable down there."

In view, however, of the difficulties of securing a sufficient supply of laborers for so great a work, and of regulating their wages, the Commission has concluded to increase the actual average prices paid at Chicago by 33⅓ per cent. for all earth and rock work on the western division and by 50 per cent. for work on the eastern division, after allowing an increase of 10 cents for rock on the eastern division because of local differences and character of material.

The prices applied to the quantities will therefore be as follows:

On the East Side.

For Greytown harbor, dredging	$ .25	per cu. yd.
For Greytown harbor, jetties.	2.50	" " "
For dry earth excavation....	.44	" " "
For solid rock excavation....	1.30	" " "
For dredging in upper river..	.30	" " "
For dredging in lake	.20	" " "
For rock under water.....	5.00	" " "
Timber cribs	3.25	" " "
Clay puddle and back filling, exclusive of cost of excavation	.50	" " "
Concrete in structures other than locks	8.30	" " "
Concrete in locks.....	7.23	" " "
Stone pitching on embankments	2.00	" sq. yd.
Timber in structures	60.00	" M.B.M.
Clearing	75.00	" acre.
Clearing and grubbing.....100.00		" "

On the West Side.

For dry earth excavation....$	.39	per cu. yd.
For solid rock excavation....	1.03	" " "
For dredging harbor.....	.20	" " "
For rock under water.....	5.00	" " "
For jetties	2.00	" " "
Timber cribs	3.00	" " "
Clay puddle and back filling, exclusive of cost of excavation	.50	" " "
Concrete in structures other than locks	8.30	" " "
Concrete in locks.....	7.23	" " "
Stone pitching on embankments	1.75	" sq. yd.
Timber in structures	60.00	" M.B.M.
Clearing	75.00	" acre.
Clearing and grubbing.....100.00		" "

The prices for structural work of locks and weirs are based on the cost of similar work in the United States, to which 33 per cent. has been added for difference of location, including climate, etc.

Feasibility.

Under this division of the subject, the Commission would respectfully submit that it has failed to find any competent authority that denies the feasibility of constructing a canal across Nicaragua.

The feasibility of the canal is conceded for the following reasons:

1. There are at this date sufficient precedents for ship canals capable of passing the largest vessels, so that any question of the navigation of such a channel is eliminated.

2. The ability to construct and operate locks of the requisite dimensions is sufficiently established by existing structures on the Manchester and Keil canals, at Davis island on the Ohio, and at the St. Mary's canal, Michigan.

3. The possibility of constructing the necessary dams, weirs, sluices and embankments, which shall be sufficiently stable and impermeable to control the water required for navigation, as well as to regulate the floods, is within the resources of the engineering profession and is fully demonstrated by the many hundreds of miles of embankments, levees and dams, both at home and abroad. There is no reason to doubt the ability to build them out of the native rocks and earth and to give them the required strength and tightness to retain or to discharge the water with safety.

4. There is no question as to the adequacy of the supply of water for all purposes at all seasons nor as to its control in times of flood.

5. Neither is there any doubt with reference to the ability to secure good supporting ground for the trunk of the canal nor suitable sites for locks and dams.

6. The harbor question is only a matter of money and it is believed that good, capacious and safe artificial harbors can be created at a

reasonable cost. In brief, this Commission sees no reason to doubt the entire feasibility of the project, but it realizes the necessity of exercising due care in the preparation of the specifications and in the conduct of the work, that the details of construction be thoroughly inspected and properly executed under competent supervision.

ESTIMATE.

After a careful analysis and comparison of the physical features and quantities affecting the numerous variants, the Commission has selected that route which it believes will give the best results.

This route, starting from the harbor at Greytown, crosses the coastal plain, passes to the north of Lake Silico, and up the left bank of the San Juan to the dam at Boca San Carlos, thence follows the improved river channel, crosses the lake, and traverses the valleys of the Lajas and Rio Grande to Brito on the Pacific.

It is characterized by 6 locks on the eastern division, having a lift of 18.41 feet, all lying east of the dam, and 4 locks on the western division, having a lift of 29 feet. The summit level extends from the lock .43 of a mile east of the beginning of the cut at Boca San Carlos to the lock 1.86 miles west of Buen Retiro, a distance of 139.3 miles.

The details of the estimates are stated in the reports of the assistants hereto appended, and it will suffice here to summarize and classify the quantities for the excavation of the canal trunk and to affix their unit prices in order to ascertain the approximate cost. The auxiliary works have also been computed for each subdivision separately and in detail, but the totals only are stated in this connection. The calculations are based upon a minimum elevation of 104 for the summit level, with a depth of 30 feet and a minimum bottom width of 150 feet, as set forth more particularly under the "Dimensions of the Canal."

GENERAL ESTIMATE OF COST.

East side, with 50 per cent. over Chicago prices for earth and rock.

Classification.	Cu. yds.	Price.	Amount.
Earth	23,206,836	at $ .44	$10,211,007.84
Rock	1,309,375	" 1.30	1,702,187.50
Rock under water	472,705	" 5.00	2,363,525.00
Dredging (harbor)	10,748,900	" .25	2,687,225.00
Dredging (lake)	17,308,850	" .20	3,461,700.00
Dredging river & canal	46,555,742	" .30	13,966,722.60
Dredging upper river	15,183,100	" .39	5,921,409.00
	114,785,508		$40,313,846.94

West side, with 33⅓ per cent. over Chicago prices.

Earth	21,949,472	at $ .39	$ 8,560,294.08
Rock	6,264,617	" 1.03	6,452,555.51
Rock under water	281,673	" 5.00	1,408,365.00
Dredging harbor	9,500,000	" .20	1,900,000.00
	37,995,762		$18,321,214.59
	152,781,270		$58,635,061.53

AUXILIARY WORKS.

Classification.	Cu. yds.	Price.	Amount.
Amount brought forward			$58,635,061.53
Jetties, Greytown	550,000	at $2.50	$ 1,375,000.00
Jetties, Brito	144,107	" 2.00	288,214.00
			$ 1,663,214.00
Concrete dam and regulating works at Boca San Carlos			4,570,340.00
4 locks on west side, 28 feet lift			7,412,580.00
6 locks on west side, 18.41 feet lift			9,560,400.00
Weir on west side, Buen Retiro			1,102,300.00
Weirs on east side below San Carlos			207,890.00
Clearing and grubbing (7463 acres)			615,625.00
Guard gates, timber piers, piling, etc			1,089,343.00
			$24,558,478.00
			$84,856,753.53

MISCELLANEOUS.

100 miles of R. R. for construction purposes, at $50,000 per mile (double track)	$ 5,000,000.00
Sanitary and police	2,000,000.00
For maintenance of harbors during construction of canal, and for buoys, beacons and lighting	1,000,000.00
	$92,856,753.00
Engineering and administration, 6 per cent.	5,571,405.00
	$98,428,158.00
General contingencies, 20 per cent	19,685,632.00
TOTAL	$118,113,790.00

For the cost of engineering and administration an estimate of 6 per cent. has been made. This estimate is large, but in a work of such great importance, the engineering and superintendence must be thoroughly and carefully done by men of ability and integrity who will necessarily command higher rates of pay than would be deemed sufficient in the United States.

An estimate of 20 per cent. for contingencies has been made. It is intended to cover all items of expense due to unforeseen accidents or emergencies. Owing to the extent and character of the work, there are more uncertainties than usual, including that of labor, which will have to be largely imported from the islands of the West Indies and from our Southern States. No work of this character and importance has ever been completed within the tropics. There is, therefore, nothing to serve as a precedent or guide for the proper contingent percentage, but after careful consideration and with a desire to make an ample allowance, the Board has decided

to include an estimate of 20 per cent., which is believed to be quite sufficient for all probable accidents or emergencies.

It is believed that if honestly and properly administered, with money at command as required, the canal can be built within the limits of the above estimate.

Conclusions.

The Commission after mature deliberation has adopted and estimated for the route from Brito to Lake Nicaragua, called Childs' route, variant No. 1, and from the lake to Greytown, that called Lull route, variant No. 1. This line leaving Brito, follows the left bank of the Rio Grande to near Buen Retiro, crosses the Western Divide to the valley of the Lajas which it follows to Lake Nicaragua. Crossing the lake to the head of the San Juan river, it follows the upper river to near Boca San Carlos, thence, in excavation, by the left bank of the river to the San Juanillo, and across the low county to Greytown, passing to the northward of Lake Silico. It requires but a single dam, with regulating works at both ends of the summit level.

The new location selected for the dam at Boca San Carlos eliminates one of the most serious engineering difficulties by avoiding entirely the San Carlos river with its torrential floods and large volume of sediment, and by locking down immediately from this dam the difficulties and risks of the high embankments of the Menocal line are also avoided.

Instead of the dam at La Flor a lock and regulating works have been substituted at Buen Retiro where the topography is well adapted for the purpose. It is also proposed to divide the surplus waters of the lake basin between the east and west sides, thus reducing the velocities in the San Juan and securing ample waste-way capacity for the maximum discharge that can ever occur, if stored and distributed over a short period of time. Ample provision has also been made for a possible fluctuation of the lake of 6 feet or more without injury to property, by fixing the elevation of the bottom of the canal sufficiently low to cover seasons of minimum rainfall. The surveys have in general revealed better physical conditions than were hitherto supposed to exist, especially as to the amount of rock in the upper river, whereby it is possible greatly to reduce the estimated cost of construction. This fact will account largely for the comparatively moderate amount of the estimate when the enlarged dimensions of the project are taken into consideration. Other reductions are due to the improved methods and machinery available, as developed on the Chicago drainage canal, and which cannot be ignored in discussing a work of this magnitude.

The creation of sufficiently capacious interior harbors presents no unusual difficulties, and they can be secured at a reasonable cost.

The field work, under the authority of this Commission, has been carefully and well done, and is believed to be all that is necessary for the preliminary location of a canal, and to determine, within narrow limits, the final location of dams, locks, and other constructions. Should a canal across Nicaragua be authorized, it will be necessary to make further minute and careful investigations by borings to determine the exact location of locks and dams, for which this Commission had neither the time nor money, nor would it have been justified in doing work of this character until the construction of a canal was assured. The computations of amounts to be excavated have been carefully made and checked to guard against errors and are believed to be accurate within narrow limits. All pos-

sible information has been sought with regard to cost of similar work in the United States and in Central America, and a careful comparison made of the probable differences between Nicaragua and the United States.

To determine the proper unit prices for excavation the average of prices actually paid to contractors on the Chicago drainage canal, which represent cost of plant, prices paid for work done, and contractors' profits, were taken. Up to this point the Commission dealt only with facts. To the prices paid at Chicago certain percentages have been added for the difference in location, climate, etc., etc. These percentages are, of course, a matter of judgment, upon which men may honestly differ. But from all the information obtainable by this Commission and after careful consideration, with a desire to arrive at a proper conclusion, those used in the estimate are deemed fair and reasonable.

In obtaining the estimate for cost of locks the prices actually paid for building the Government locks at the Sault Ste. Marie were taken, and 33 per cent. was added for the difference of location. This percentage is believed to be ample, as a large part of the expense of constructing the locks will be for material, much of which can be furnished in Nicaragua at the same or only a small advance upon the prices in the United States.

After giving due weight to all the elements of this important question and with an earnest desire to reach logical conclusions, based upon substantial facts, the Commission believes that a canal can be built across the isthmus on this route for a sum not exceeding that stated in the estimate.

The dimensions of the canal proposed are much larger than any hitherto considered and will be ample not only to meet the present requirements of commerce but also for many years to come. A navigable channel of smaller dimensions than those proposed, only sufficient for present needs, can be constructed for a lesser sum if deemed expedient.

We have the honor to be, Sir,

Your obedient servants,

J. G. Walker,
Rear-Admiral, U. S. Navy,
President of Commission.

Lewis M. Haupt,
Civil Engineer, Member.

In appending my signature to this report, I desire to state that I concur generally with the views expressed, but my estimate of the cost is $134,818,308.

Peter C. Hains,
Colonel, U. S. Corps of Engineers, Member.

APPENDIX I

REPORT OF E. S. WHEELER

CHIEF ENGINEER

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APPENDIX I

WASHINGTON, D. C.

REAR-ADMIRAL J. G. WALKER, U. S. Navy,
President Nicaragua Canal Commission,
Washington, D. C.

Sir:—I have the honor to submit the following report of operations connected with the Nicaragua Canal Commission:

The expedition sailed from New York December 5, 1897, on the U. S. Gunboat "Newport." There were on board, the Commissioners and sixty-nine employés. The expedition landed at Greytown December 18. On the 21st I received your instructions to "take charge of the field work and direct the operations of the various parties."

The force was divided into eight parties with the following organization and instructions:

Dr. C. W. Hayes, from the U. S. Geological Survey, was directed to take charge of the geological work, including the earth and rock borings. There were assigned to him the following assistants:

Ignatius O'Reardon,	Moriz Bernstein,
Harry Spence,	W. E. Herbert,
P. Tierney,	E. F. Fischer,
T. J. H. Archambault,	E. P. Humphrey.

Mr. A. P. Davis, also from the U. S. Geological Survey, was directed to take charge of the hydrology and meteorology. There were assigned to him the following assistants:

R. C. Wheeler,	G. P. Philip,
D. H. Baldwin,	H. W. Miller,
W. M. Barton,	G. R. Wadleigh,
F. C. Green,	R. Breese,
H. S. Reed,	Neil P. Leary.
W. W. Schlecht,	

Mr. J. W. G. Walker was directed to make a topographical survey of the west side. The following assistants were assigned to him:

E. B. Harden,	L. R. Lee,
M. A. Coroalles,	J. A. Bull,
H. C. Hurd,	P. H. Belknap,
C. P. E. Peugnet,	J. D. Forster.
O. B. Powell,	

Mr. George W. Brown was directed to make a survey of the San Juan river, beginning at Lake Nicaragua. The following assistants were assigned to him:

S. S. Evans,	E. G. Nicewarner,
C. L. Hammond,	Thaddeus Merriman,
Lester Bernstein,	G. H. Williams.
F. R. Torrington,	

Mr. H. H. Trundle was directed to make a survey of the Canal Company's route from Greytown to Ochoa. The following assistants were assigned to him:

A. J. Norris,	W. A. Smith,
L. F. McNeil,	Dion Martinez.
P. J. Brune,	

Mr. Boyd Ehle was directed to make a survey for a dam at Tambor Grande and an embankment southward to the Costa Rican highland. The following assistants were assigned to him:

O. A. F. Saabye, E. G. Heyl,
L. S. Snyder, T. F. Boltz.
J. C. Elson,

Mr. Andrew Onderdonk was directed to make a survey of the San Juan river beginning at Greytown. The following assistants were assigned to him:

W. G. Fitzgerald, W. D. Thomas,
R. N. Begien, John Carmichael,
L. E. Lannan, A. V. Montes.

Messrs. F. L. Stuart and Stephen Harris were directed to run separate lines of precise levels from the Caribbean sea to the Pacific ocean. The following assistants were assigned to them:

J. O. Jones, J. A. Mitchell,
R. B. Post, G. F. Seymour,
Sherwood Wilson, L. W. Mohun.

Mr. F. P. Davis was directed to build a line of camps along the Canal Company's route from Greytown to Ochoa. Mr. George J. Smart was assigned to him as an assistant.

Mr. H. C. Miller was assigned to the Chief Engineer as First Assistant.

Mr. J. Crowninshield was given charge of supplies and warehouse at Greytown. He was assisted by Mr. J. H. Barnard.

The following gentlemen were sent out from the United States later and were distributed among the field parties on their arrival:

C. H. Stockton, H. W. Durham,
H. C. C. Shute, J. C. Taylor,
R. Morrin, H. E. Anschutz,
John Stockton, L. Hankins,
H. F. Collins, A. S. Miller.

The following gentlemen were employed in Nicaragua and distributed among the parties:

A. L. Scott, J. A. Austin,
Alfred Ahrling, A. E. L. Pain,
George Challice, Fred. Davis,
H. E. Webb, E. T. Vargas,
F. H. Davis, F. D. Glenny.
Charles Hayman,

Mr. Brown was recalled to the United States shortly after he began work. Mr. Stuart was put in charge of his party and Mr. Harris took entire charge of the precise leveling.

Late in the season a new topographical party was organized and Mr. Martinez put in charge of it; after one month he was replaced by Mr. Evans. There were no other changes among chiefs of parties, though the exigencies of field work made many changes necessary among the subordinate members.

The several parties completed the field work assigned them as follows: Mr. Boyd Ehle in August, 1898; Messrs. Miller, Onderdonk, Trundle and the Chief Engineer returned to the United States in September; Messrs. Walker and Hayes in October; Mr. Harris in November; Mr. Stuart in December; and Mr. Evans in February, 1899.

Mr. A. P. Davis returned in October, 1898, leaving his party in the field under the charge of Mr. Hurd, who still remains in Nicaragua.

The work done and the results obtained by each of the parties are given in detail in the attached appendices.

A brief and general outline of the aggregate results is as follows: The geology of the country has been sufficiently developed so that a trustworthy geological map of the Nicaraguan valley has been made. The material along the line of the various canal locations has been classified with sufficient accuracy for a preliminary

estimate. Earthquakes and other seismic disturbances have been investigated with reassuring results. The rainfall has been measured continuously for more than a year at twelve different stations. The discharge of all important streams in the entire drainage basin has been measured, both at high and low water, and the amount of sediment transported by them determined. Evaporation observations have been made at different places.

The probable maximum discharge of all important streams has been deduced from their flood-plains and such old records as were available.

The fluctuations of Lake Nicaragua, its evaporation, inflow and outflow have been continuously observed for more than a year. Their maximum values have been deduced from the elevation of flood-plains and lake beaches, and from former observations. A similar study has been made of Lake Managua. The possibility of diverting certain streams into Lake Managua has been investigated and the cost estimated.

On the west side a topographical survey has been made of the valleys of the Rio Grande and the Lajas and the connecting pass between their headwaters. This survey has been made with sufficient minuteness so that locations and estimates can be made directly from the map.

A topographical survey of the San Juan river has been made from the lake to the sea, including all of its distributaries and the lower reaches of its principal tributaries. (The hydrography between the lake and Castillo was done by Lieutenant Hanus of the Navy, and was not under my charge.) This survey has been made with sufficient accuracy so that wherever the river is canalized the location of the channel and the estimate of material can be made directly from the map.

Probable dam sites have been more minutely developed.

A survey has been made of Lake Nicaragua, showing the shore line and soundings.

An outline survey has been made of Lake Managua.

A survey has been made for a dam at Tambor Grande and an embankment line running southward to the highlands of Costa Rica.

A resurvey has been made of the Maritime Canal Company's proposed route from Greytown to Ochoa. This survey has been made with sufficient detail so that an accurate estimate of the amount and classification of material can be made. Surveys for a canal location have been made from the mouth of the San Carlos river to Greytown. From the source of the San Juanillo to the sea three different lines have been run. All of these surveys have been made with sufficient accuracy for an estimate along the lines themselves, and in most places the topography has been so well determined that new locations and estimates can be made from the map.

An investigation has been made of the movement of sand along the shore of the Caribbean sea between Port Limon and Monkey Point.

A duplicate line of precise levels has been run from Greytown to Brito. Tide gages have been read for several months at both places, so that the difference in the elevation of the two oceans is quite accurately known.

In addition, hydrographical surveys of the coast in the vicinity of Greytown and Brito were made from the U. S. Gunboats "Newport" and "Alert." This work was not under my charge.

The aggregate results of this field work, when combined with the results of previous canal surveys, together with all other existing data, are

sufficient to sharply define the limits of the "canal region" and to present the important physical features of this region which relate to canal construction.

The limits of the canal region and its salient physical features will first be presented.

Topography and Physics.

The following discussion of the topography and physics of the Nicaraguan valley is for the purpose of determining, first, the limits of the canal region; and, second, such physical features of this region as relate to canal construction.

Much of the data in this discussion is taken from the attached appendices. The geology is derived entirely from the report of Dr. C. W. Hayes, the hydrology from the report of Mr. A. P. Davis and the topography, hydrography, sand movement, etc., from the reports of the assistant engineers.

By the term "canal region" is meant the region in which a canal may be built at a cost so much less than elsewhere that no other locality need be considered. Professor Keasbey has termed this "the region of comparative feasibility."

It is assumed, without discussion here, that no canal route is practicable or need be considered that does not pass through Lake Nicaragua and use it for its feeder and summit level.

The canal region is shown on Map No. 2 in red. It will be seen to be a very narrow strip for two-thirds of its length. In the remaining third it expands to a width of fifteen or twenty miles. All of the proposed canal routes lie within this region, and it will be shown that none outside of it are as good. (If there were a complete and accurate topographical map of the entire country, this fact would become apparent by a simple reference to it. In the absence of special knowledge derivable from such a source, evidence must come from the consideration of general laws sufficiently convincing to those familiar with the conditions.)

For convenience, the country bordering on the canal region will be considered in three parts. The first part lies south of the San Juan river and is limited on the south by the foot-hills of the Costa Rican mountains.

The second part lies north of the San Juan river and between Lake Nicaragua and the Caribbean sea.

The third part is the narrow strip of land lying between Lake Nicaragua and the Pacific ocean.

In the present discussion it is not intended to give a complete analysis of the topography and physics of the entire Nicaraguan valley; only such points will be considered as relate to the location of a canal and tend to permit or prevent its construction.

A reference to the accompanying map will show that the portion of the Nicaraguan valley which lies between the San Juan river and the foot-hills of the Costa Rican mountains is crossed by a number of rivers, some of them of considerable size. The San Carlos is the largest. The Sarapiqui, Frio and Poco Sol are streams of considerable size. An inspection of the map shows that these streams have their sources in the Costa Rican mountains and flow in a northerly direction across the plain into the San Juan river. They have a swift current but no falls or great rapids below the foot of the mountains.

An examination of the map shows that a canal location from the Caribbean sea to Lake Nicaragua, south of the San Juan river, would cross all of these streams. This would make its construction practically an impossibility. The ex-

istence of these streams is deemed entirely sufficient to exclude from the canal region all that part of the Nicaraguan valley lying south of the San Juan river. The southern boundary of the canal region on the eastern side is then the south banks of the San Juan and Colorado rivers. Before leaving the discussion of the southern part of the valley a few points will be mentioned that relate to and assist in elucidating the topography north of the river. An inspection of Map No. 1, Sheet No. 2, shows that the material of this southern part of the Nicaraguan valley is volcanic ejecta and alluvium. The alluvium is found at the eastern and western ends of the valley, where it borders on the Caribbean sea and Lake Nicaragua. The volcanic material was ejected from the line of Costa Rican volcanoes and flowed down to the northward, until it met the older plain which slopes from the north, southward. A reference to Map No. 1, Sheet No. 2, will show that the San Juan river does not exactly follow the junction of these two plains but cuts through the southern portion of the northern plain, leaving a few of the older hills south of the San Juan. Of these hills, those at the junction of the San Carlos with the San Juan are most conspicuous, having an estimated height of more than 1100 feet.

The second part is the region lying north of the San Juan river and between Lake Nicaragua and the Caribbean sea. A reference to Map No. 1 will show by the sources of the streams that there is a crest-line or divide which is nearly parallel to the eastern shore of Lake Nicaragua and about twenty miles distant. If the narrow strip of land between Lake Nicaragua and the Pacific were removed, this crest would become the Continental Divide. This was probably the case until quite recent geologic times, and the shape of the Pacific shore, before the outbreak of the Nicaraguan volcanoes, was somewhat as shown on Plate No. II, Appendix II. This is mentioned here because the country between Lake Nicaragua and the Caribbean sea is much older than the Nicaraguan volcanoes, and much of its surface configuration was made before Lake Nicaragua was cut off from the sea. With this condition in mind it becomes easier to understand certain features of the topography. The streams east of the Divide run in an easterly direction to the Caribbean sea; those west of the Divide run in a southwesterly direction to Lake Nicaragua. It will be observed that the direction of this drainage is about parallel to the course of the San Juan and at right angles to that of the country south of the river. This is an indication that the two plains north and south of the river are essentially dissimilar and that they were formed at different times and by different causes.

It is also very fortunate for canal purposes that no large rivers flow into the San Juan from the north. The importance of this fact will be referred to later. In addition to the two plains which slope to the sea and the lake, there is a third important line of descent not shown on the map, and this is the Divide itself. In the northern part of Nicaragua the summits along this crest-line reach an elevation of five to seven thousand feet. Following the Divide southward, its elevation steadily diminishes until it crosses the San Juan in the vicinity of Castillo and is soon lost in the Costa Rican plain.

Referring again to the map, it will be seen that the shortest distance between Lake Nicaragua and the Caribbean sea is less than sixty miles, while the canal route is about one hundred miles. It will also be seen that the streams and consequently the valley lie in a generally east and west direction, or favorable for a canal

route. The question, then, whether or not this shorter route can be utilized becomes an important one; and if this narrowest part of the isthmus is excluded from the canal region it should be for a sufficient reason. That reason is the elevation of the dividing ridge between the lake and the sea. The proof that there are no low passes through this divide is quite conclusive. Some of the evidence is as follows: When the San Juan first overtopped and broke through the pass at Castillo, it was at least fifty feet higher than it is now. The evidence that it has been eroded and cut down fifty feet is ample. Since the water would find the lowest pass, it is evident, therefore, that there is no other pass that is not at least fifty feet higher than the present river valley. Again, it has been mentioned that in the northern part of Nicaragua the summits of this ridge are seven thousand feet high, while the intermediate valleys have elevations of two and three thousand feet. Both the summits and the valleys slope quite uniformly to the southeast until both are lost in the Costa Rican plain. The rate of this descent is about ten feet per mile for the valleys. Therefore, if this ridge be followed from Castillo in a northwesterly direction, the average height of its valleys or passes will increase at the rate of about one hundred feet in ten miles. So far as observations go, this seems to be the case. Perhaps the most convincing proof of the considerable elevation of this ridge is the actual observations that have been made. In this country, without roads, the streams are used as thoroughfares. All of these streams are continually traveled by rubber hunters and explorers of all kinds. The invariable report of these men is that for the first five or ten miles from the sea the current is sluggish; after that it is found to be rapid all the way to its source, indicating that all of the larger streams have their sources in elevations of not less than three or four hundred feet. The small streams that flow into the San Juan from the north are rapid in their upper reaches and soon rise to a considerable elevation. Again, the summit of this ridge when seen from a distance, shows a uniform slope to the southward, but with no indication of notches or low passes in it. The cumulative evidence of the height and continuity of this ridge is sufficient to exclude from the canal region all of that country lying north of the San Juan, except the narrow valley of the river itself, from the lake to the San Juanillo and the broader delta plain from there to the sea. The northern boundary of the canal region on the east side is, therefore, as shown in Map No. 2.

The third section is the narrow strip of land lying between Lake Nicaragua and the Pacific ocean. It will be seen that the canal region here occupies the valleys of the Rio Grande and the Lajas. The route is seventeen miles long. The greatest elevation is about forty-five feet above Lake Nicaragua. This country is traversed by roads in every direction. It is quite accurately mapped. All the lower passes have been examined, and the evidence is complete and convincing that the route chosen is through much the lowest pass between the lake and the ocean, and that the cost is much less here than by any other route. This conclusion has been reached through actual surveys and observations. The boundaries of the canal region on the west side are, therefore, as shown on the map.

The physical reasons which limit the canal region may be briefly summarized as follows: On the east side the country south of the San Juan river is excluded by the large rivers which cross it. The country north of the valley of the

San Juan river is excluded by the range of high hills which crosses it in a northwesterly and southeasterly direction. This leaves for the canal region on the east side only the narrow valley and delta plain of the San Juan river.

On the west side the country both north and south of the valleys of the Rio Grande and Lajas is excluded by the range of high hills which form the Continental Divide.

The character and importance of this region may be illustrated and emphasized by the statement that it is believed that any canal location wholly outside of it would cost at least five times as much as a similar canal properly located within it.

The boundaries of the canal region having thus been determined, the physical features of the region itself will next be considered.

On the west side it is made up of the valleys of two small streams and the low pass connecting them. The Rio Grande flows into the Pacific. Its observed maximum discharge is 2975 cubic feet per second. Its minimum discharge is almost nothing. This river has, in former times, been much larger than now and has worn a corresponding channel. This old channel has been silted up and the present smaller river has cut its way through the silt, using only a portion of the old river bed. It is probable that this old river was the outlet for a time of Lake Nicaragua. Eventually the San Juan river cut back through the Divide at Castillo and turned the drainage of the lake to the Caribbean sea. Whatever the cause may have been, the old river bed is here and diminishes to a considerable extent the rock-cutting in the channel. The probability that the outlet of Lake Nicaragua was at one time on the Pacific side is of interest and some importance and will be referred to later. The Rio Grande at times carries considerable sediment. It shows, however, no signs of a delta. The coast in the vicinity of its mouth is defended by a series of rocky promontories. Between them the sand and alluvium are shaped by the sea into a slightly concave shore line, which appears to be practically permanent. The shore where the Rio Grande discharges into the sea shows no changes from the earliest maps. The sea floor is quite steep, the seven-fathom curve being about 1300 feet from the shore. The tides have a range of about nine feet.

The Lajas is a small stream flowing into Lake Nicaragua. It carries some sediment. The bottom of the lake at the mouth of this stream is quite steep, the six-fathom curve being about 4000 feet from the shore.

The first seven miles of the canal region on the west side, beginning at Brito and going eastward, are the flood-plain of the Rio Grande. This plain is quite irregular in shape. It has a seaward slope of about ten feet to the mile. The alluvium of which it is composed varies from forty to one hundred feet in depth. It is partly under cultivation but generally wooded. It is the most fertile and beautiful valley in the canal region. From the head of this valley to Lake Nicaragua is about ten miles. The excavation for the canal here is almost entirely through rock. The average thickness of the earth on the rock is about six feet. The rock is shale and sandstone, much broken and easy to excavate. This part of the canal region is quite narrow, the hills approaching closely on each side.

Lake Nicaragua.

This lake is about one hundred miles long and forty-five miles wide. It has an area of about 3000 square miles. Its greatest depth is two hundred feet. It is about one-third the size of Lake Erie. The length of the sailing line,

between the points where the canal enters and leaves it, is about seventy miles. Its total drainage area is 12,900 square miles. Its inflow during periods of great rainfall is sometimes sufficient to raise the surface six inches in forty-eight hours. The maximum calculated outflow is 50,000 cubic feet per second. Its evaporation is estimated to be about five feet annually. During the dry season the evaporation exceeds the inflow. During exceptionally dry years the evaporation exceeds the inflow for the entire year. This causes considerable fluctuation in the elevation of its surface. It is reported as having been as low as ninety-seven feet above sea level and as high as one hundred and twelve. These reports or traditions are somewhat uncertain. It is, however, reasonably certain that it fluctuates between one hundred and one hundred and ten above sea level, at no very infrequent intervals. Its depth along the proposed sailing line is ample except for thirteen miles on the east side. Here submarine excavations will be necessary. Borings show that the material to be excavated is silt.

Earthquakes.

Before considering the east side some of the salient facts connected with earthquakes will be mentioned. In the northwestern part of Nicaragua slight earthquakes are frequent. Scarcely a month passes without one or more being noticed. The center of these disturbances is always near the line of the Nicaraguan volcanoes. The line of volcanoes begins with Madera at the southern end, in Lake Nicaragua, and terminates with Casiguina at the northern end near the Gulf of Fonseca. This country is geologically very recent. The great seismic disturbance which caused this upheaval has nearly passed. Nearly all the volcanoes are extinct; only two or three are still smoking. It is believed that this is an era of subsidence and that earthquakes and other seismic manifestations will continue to grow lighter and finally cease altogether. Again, the canal route is entirely south of the earthquake area. In the historic period there have been no earthquakes in the canal region of sufficient violence to injure canal structures. It is believed that the danger from earthquakes here is now no greater than in any other seacoast region.

East Side.

The physical features of the east side will next be considered. It has already been stated that the canal region is only the narrow San Juan valley and its broader delta plain. The controlling physical feature of this region is the San Juan river. At one time it was separated into two parts by the Continental Divide crossing at Castillo. One part flowed eastwardly into the Caribbean sea and the other westwardly into the Pacific ocean. This condition was so recent that many of its topographic and hydrographic effects still remain, some of them having an important bearing upon canal work. The western branch had its sources west of Castillo and was formed by the junction of the Poco Sol and the Savalos rivers. It then flowed westwardly and emptied into the Pacific ocean near where Madera now stands. An inspection of the map of Lake Nicaragua shows two sections of this old river valley not yet silted up; one in the vicinity of Madera and the other near Solentiname. This latter will be utilized for canal purposes. It will be noticed that the depth of this submerged river valley is considerably below sea level, showing that at the time it was formed the land stood higher than now. The southern end of Lake Nicaragua has been so silted up that a consid-

erable portion of this old channel is concealed. Its old location can, however, be determined by boring. The single line of borings between the mouth of the lake and Castillo shows it in many places. It is probable that considerable rock excavation can be avoided by properly developing this old channel and following it with the canal, rather than the present river bed. An inspection of the map shows that all the tributaries of the San Juan river west of Castillo still run westwardly in their lower reaches as they did when they ran to the Pacific ocean. The eastern branch had its sources on the east of Castillo and was formed by the junction of the Bartolo with other small streams and flowed eastwardly to the Caribbean sea in nearly the same channel that it now occupies; except perhaps through the delta plain. Its bed has been developed by borings in a number of places. Its seaward slope seems to have been quite uniform with a gradient of about four feet per mile, which is much steeper than the present river bed. The Machuca rapids must have had a fall of about fifty feet more than at present, because immediately below Machuca the bottom of the old river bed is found to be about fifty feet lower than at Machuca. There still remains one section of this old channel that has not yet been completely silted up. This is between Machuca and the mouth of the San Carlos river. This is called Aguas Muertas, or dead waters. There are soundings in this reach that go below sea level. This channel, like the one on the Pacific slope, is very deeply worn, thus indicating again that the land must have stood higher at that time than at present. The tributaries to this branch turn eastwardly in their lower reaches. The present San Juan has, therefore, two sets of tributaries, those of the lower half, flowing eastwardly in the normal direction, and those of the upper half, flowing westwardly or opposite to the direction of the main stream.

Volume and Tributaries.

The San Juan river as it is at present is about one hundred and twenty miles long. Where it leaves Lake Nicaragua its estimated maximum discharge is fifty thousand cubic feet per second; above the mouth of the San Carlos it is one hundred thousand. When it enters the Caribbean sea the estimated maximum discharge of all its distributaries is three hundred thousand cubic feet per second. This makes the upper San Juan river a stream comparable in maximum volume with the St. Mary's river or the Potomac at the head of tidewater, and the lower San Juan comparable with Niagara or the Susquehanna at Harrisburg. The two principal tributaries are the San Carlos with an estimated maximum discharge of one hundred thousand cubic feet per second and the Sarapiqui with an estimated maximum discharge of sixty thousand cubic feet per second. The reason that so large a river is possible in so small a drainage basin is the enormous rainfall. In the country between Lake Nicaragua and the Caribbean sea the average annual rainfall is about fifteen feet. The average annual evaporation from the land surface is about four feet. This leaves eleven feet for run-off or about eleven times as deep as the average run-off in the United States east of the Mississippi. Again, the valley is so small that flood-waters are precipitated very quickly into the main river.

When the San Juan first leaves the lake it is almost wholly free from sediment, but very little is added above the San Carlos. This is evident from the fact that the deep channel through the Aguas Muertas has not yet been silted up. The San Carlos carries large quantities of sand, and

from its junction to the sea the San Juan is heavily laden with sand. At the head of the delta plain the San Juan separates into several distributaries. The Colorado is the principal stream and carries perhaps four-fifths of the water. The lower San Juan is next in importance. It has a small branch called the Tauro. The San Juanillo leaves the main river and, after a circuitous curve of about twenty miles, rejoins it again. The Caño Bravo is a branch of the Colorado. The Parado is a small stream that leaves the lower San Juan and flows into the Agua Dulce lagoon.

Character of Bed of River.

From the lake to near Castillo the river bed to a depth of thirty feet or more is earth, being chiefly silt, sand and clay that has been deposited in the old river bed, which has already been described and which was much deeper than the present one and sloped westwardly to the Pacific ocean. From a little above Castillo to a little below Machuca, a distance of about fourteen miles, the river flows over a bed of sandstone rock in practically the same channel that it has always followed. This part of the river has never been worn down. The sandstone has resisted erosion and the river bed here is the same, or probably worn a little deeper than it was before the drainage of Lake Nicaragua was turned eastward. This is the only river section in which there will be, for canal purposes, any considerable amount of rock work. Most of the rapids occur in this section. There is a fall of thirty-seven feet in fourteen miles. At the foot of the Machuca rapids the sandstone disappears. It has previously been mentioned that the upper San Juan brings no sediment from the lake, and the small streams that flow into it carry but little. This is believed to be the explanation as to why this portion of the old channel still remains. The San Carlos carries a large amount of sand, so that from its mouth to the sea the old channel has been silted up and the San Juan now flows over a sandy bed between banks of sand.

The important features of the bed of the San Juan river may be summarized as follows: From the lake to Toro rapids the river flows in the partially silted channel of an older stream that formerly flowed westwardly to the Pacific ocean. From Machuca to the Caribbean, the river flows in the deeply-worn and partially-silted channel of an older stream that had its source near Castillo and flowed eastwardly to the Caribbean sea. Between Toro and Machuca the river flows in what may properly be called its own bed, that is, the earlier streams that flowed through this section were so small and the material over which they ran so hard, that they left no traces of their channel. The great amount of sediment and the immense floods below the San Carlos make the canalization of this part of the San Juan very difficult. Fortunately the topography is such that alternatives are possible. An inspection of the map shows that from the mouth of the San Carlos to the sea no large streams enter the San Juan from the north. The largest one is the San Francisco which has a drainage of about forty square miles. Its greatest observed discharge is two thousand cubic feet per second. Its estimated maximum discharge is four thousand cubic feet per second. This amount of water is not so great that it cannot be admitted to the canal and passed out again through sluices without serious inconvenience. There are some hills that approach close to the river but none that cannot be either cut through or passed around. There are, therefore, no serious physical objections to building a canal

along the north side of the San Juan from the lake to the sea.

Delta Plain.

The delta plain is of considerable extent. Its outlines are quite accurately shown on the map. It has a seaward slope of about one and one-half feet per mile. It is heavily wooded and for the most part marshy. There are some hills in it, mostly between Lake Silico and the Colorado river. These hills are much older than the plain. They resemble islands in a sea of alluvium. The material and surface of the delta plain are so uniform that the cost per mile of building a canal would be nearly the same in any part.

Sand Movement.

After the sand has been carried to the sea by the streams it is transported by wave action along the shore. The observed facts concerning the movement of sand along the shore in the vicinity of Greytown harbor are as follows: From Port Limon, seventy miles south of Greytown to Point of Rocks, forty miles north of Greytown, the shore is formed of a coarse black sand of volcanic origin. In places this sand is known to extend two or three miles inland. The hydrographic map of the coast between the Colorado and the Indio rivers shows that it extends seaward to between the seven- and eight-fathom curves. None is shown beyond the eight-fathom curve. To the northwest of Greytown the amount of sand along the shore steadily diminishes, until at Point of Rocks it disappears entirely. This sand is at present being brought to the sea by all the streams having their sources in the Costa Rican mountains. The Colorado and the San Juan carry considerable quantities which are obtained from the San Carlos and the Sarapiqui. The streams north of the San Juan do not carry any. A considerable amount of this sand stops in and about Greytown harbor. This quantity has been computed by Professor Mitchell, by the Board of 1895, and by Professor Haupt. All have found it to be about seven hundred and fifty thousand cubic yards annually. An examination of old maps shows that at the point where the Maritime Canal Company's harbor is located, the six-fathom curve has been pushed seaward at an average rate of seventy-five feet per annum since 1809.

Dr. Hayes has pointed out that temporary harbors have been formed several times near where Greytown now stands. The first one of these was Lake Silico. It was at one time a sheltered bay. Some of the hills which now surround it were then islands. The silt and northward-moving sea drift finally shut it off from the sea. Then other harbors were successively formed in front of Lake Silico. The several long parallel lagoons still show the sites of these harbors. The last one, which has been known as Greytown harbor, has been entirely formed and closed within the historic period. The first trustworthy map of the vicinity was made in 1809. At that time the sand spit had pushed out from harbor head about three-quarters of a mile. If its rate of growth or accretion before that time had been the same that it was afterwards, it must have begun about the middle of the last century. In 1809 there was a small but deep and safe harbor behind the sand spit. The lengthening of this sand spit was very uniform, until in 1852 it reached the mainland, and the harbor of Greytown was converted into another lagoon. At present there are no definite signs of the beginning of another sand spit. It may or may not be that the form of the shore is now such that this process will not be again repeated. The littoral current off

this coast is for the most part southward. On the hydrographic charts it is so marked with a velocity of from one to two knots per hour. During the year 1898 it ran southward about eleven months. When the trade winds were mildest the southerly current diminished and finally stopped and then flowed gently northward for about one month. I was told by the sailors and fishermen that this change in the direction of the current was expected by them each year. An inspection of the map shows that all the streams between Greytown and Port Limon have at their mouths sand spits which are turned northward. The Rio Indio north of Greytown has a sand spit now turned southward, though formerly it seems to have been turned to the northward. The inferences that have been drawn from the preceding data are as follows: There is a stream of sand moving northward along the coast between Port Limon and Point of Rocks. It is confined to the belt between the eight-fathom curve and the shore. It is, therefore, not carried by the littoral current which is for the most part southward, but is urged along the shore by wave action. The amount that has been delivered by the streams to the sea is much greater than the amount which the sea has been able to move to the northward, as shown by the fact that nearly the entire shore from Greytown to Port Limon has been built out into the sea by this sand. The volume of this sand stream is then limited by the transporting power of the waves and not by the amount delivered by the streams to the sea. The volume of the sand stream must vary in different localities because portions of it stop in the indentations of the shore. Greytown is a conspicuous example of this. Northward from Greytown the sand stream must diminish steadily until off Point of Rocks it ceases altogether. Since the building out of the shore in the vicinity of Greytown is much more rapid than it is to the northward, it is assumed that more sand stops at Greytown than passes by. It has been previously stated that the amount which stops at Greytown is known to be about 750,000 cubic yards annually. It has therefore been assumed that not more than one million cubic yards pass Harbor Head annually. This latter assumption is a conjecture and is not entitled to much weight.

If these inferences are correct it follows that any pier or jetty built out from the shore, at the proposed harbor entrance, must cross and stop this sand stream and that, to have kept the seaward end of such pier or jetty at the six-fathom curve for the last ninety years, an annual extension of at least seventy-five feet (may be much more) would have been necessary. It also follows that the further north the location, the smaller will be the volume of the intercepted sand stream.

Location.

The limits of the canal region having been found to be narrow and the region itself small, the question of location is very much simplified. But narrow and small as it is, there are several alternative locations, each having merits sufficient to demand consideration.

The canalization of the San Juan river may first be considered. It has been pointed out that the floods in the San Juan at the mouth of the San Carlos may be expected to exceed 200,000 cubic feet per second, while in the lower reaches they will exceed 300,000.

The San Carlos discharges into the San Juan a large amount of black sand which is carried by the latter river to the sea. The channel of the San Juan was formerly much deeper than

now and has been filled to a considerable depth. For example, at Upper Ochoa the black sand in the bed of the river was found to be sixty feet deep; at Lower Ochoa it was seventy feet deep; at Tambor Grande it was one hundred and fifty feet deep. Below the black sand was found in every case the solid rock of the old river bed. This shows that suitable foundations for dams can only be found at great depths.

The objections to canalizing this part of the river are its great floods, its sediment transportations and the great depth of suitable foundations for dams. These objections are not wholly insurmountable, and if there were no alternative they might be considered. It has, however, been already pointed out that there is an alternative route going across country from the mouth of the San Carlos to the sea, and that this route crosses no large streams or high hills and presents no unusual difficulties. Since it is unquestionably the better of the two plans, the canalization of the river between the mouths of the San Carlos and the Colorado will not be further considered.

The canalization of the lower San Juan from the Colorado to Greytown is feasible, because it can be cut off from the main river by a dam, thus preventing floods and sediment transportation. It will be considered later in connection with one of the locations.

The Canalization of the Upper San Juan.

It has already been pointed out that this reach of the river has flood discharges of 50,000 cubic feet per second where it leaves Lake Nicaragua, and 100,000 above the mouth of the San Carlos, that it carried but little sediment, and that its bottom between Machuca and Castillo is solid rock and near the surface, which is very favorable for dam foundations. Between Machuca and the mouth of the San Carlos the solid rock is about sixty-five feet below the surface of the river. These conditions are much more favorable for canalization than those of the lower part of the river. The flood discharge of 50,000 and 100,000 cubic feet per second through fifty miles of dredged channel, with earth banks, is the most objectionable feature. It is feared that the stream velocities caused by such floods would be sufficient to seriously erode the channel banks, and make navigation difficult. It is believed that a waste-way to the Pacific would sufficiently reduce the torrential floods so that the question of canalizing this part of the river would become a fairly simple one. Fortunately a western waste-way is possible and at a cost not so great as to be prohibitive. This question will be more fully discussed under the head of "Additional Waste-Ways."

The conclusion reached may be summarized as follows: The upper San Juan from the lake to the mouth of the San Carlos and the lower San Juan from the Colorado to Greytown, can be canalized at a reasonable cost. The remainder of the river from the mouth of the San Carlos to the mouth of the Colorado could not be canalized except at an expense that would be practically prohibitive.

The location of the canal from Lake Nicaragua to the mouth of the San Carlos is shown on Map No. 2. It is practically the river itself. It will be observed that some bends in the river are shortened by cut-offs while others are not. The question whether or not a shortening in the route is desirable has been determined by its extra cost. The following rule has governed: *Wherever the length of the canal could be shortened with an extra cost of less than one-quarter of a million dollars per mile of shortening, it has been done. When the extra cost exceeded one-*

quarter of a million dollars per mile of shortening it has not been done.

This rule has been derived as follows: It is assumed that the business through the canal will be ten million tons annually, that the tolls will be adjusted so as to produce the maximum revenue, and that the rate of interest upon the capital to be invested in the canal is four per cent. annually. The average rate for carrying freight over ocean routes of three thousand miles or more is usually assumed by statisticians to be one mill per mile-ton. Of this amount one-half is for shore expenses, loading and unloading, warehouse, insurance, etc., leaving one-half mill per mile-ton for moving freight through the water. It is assumed that vessels move at half speed in the canal. Then the cost in the canal would be one mill per mile-ton, and the cost of moving ten million tons one mile would be ten thousand dollars. Therefore, if the canal could be shortened one mile, ten thousand dollars additional tolls could be collected annually. At four per cent. this would pay the interest on one-quarter of a million dollars. Therefore, under these assumptions, one-quarter of a million dollars could be borrowed and expended without loss in shortening the canal one mile. If the shortening cost less, it would be desirable; if more, it would be undesirable. The assumptions are arbitrary. Therefore, the rule derived from them has equal, but no greater, weight than the assumptions themselves.

From the mouth of the San Carlos river to the sea several routes and variants have been considered. They are all shown on Map No. 2. They include all of the characteristic feasible routes. An infinite number of minor changes in location are possible, some of them probably profitable to some small extent. But it is believed that there is no route worthy of consideration that is not substantially included within the limits of those here given.

The locations on the west side are shown on Map No. 2. They include former locations made by the Maritime Canal Company. The Commission's location is made with reference to minimum excavation, suitable lock sites and a waste-way to the Pacific. The valleys are so narrow and the physical conditions so sharply defined that no considerable variation in location is possible. It is believed that the route chosen cannot be much, if any, improved.

Fluctuations in Lake Level.

It has already been mentioned that Lake Nicaragua has a range in elevation of at least ten feet, and there are traditions of still greater changes.

If used for a canal it is desirable to limit these fluctuations as much as possible. A very fair determination of what can be safely done in this direction, can be derived from the data now in hand. These data consist, first, of the observations made by the Commission during the year 1898. There were observed, the rainfall in the entire basin of Lakes Nicaragua and Managua; the continuous outflow from Lake Nicaragua; the evaporation from its surface, and the daily changes in its elevation. These observations are trustworthy and ample for the year. In addition there is available a rainfall record made at Rivas, continuous for nearly twenty years. Mr. Davis shows that this record appears to be trustworthy. Since the fluctuations in the lake surface are a direct and almost linear fluctuation of the rainfall, it is possible to determine what this relation is from the observations of 1898, when both rainfall and fluctuations were observed, and then apply it directly to the preceding years

when only rainfall was observed. In this way the fluctuations at any time during the last twenty years, can be determined with reasonable accuracy. The investigation has been made as follows: The observed evaporation from the lake surface in 1898 was fifty-two inches. This result is the mean of three stations around the lake. The monthly rate ranged from 6.5 inches in April to 3.1 inches in September; April being a dry month and September a wet month. 1898 was an unusually wet year. It has been assumed by Mr. Davis that in a dry year the evaporation from the lake surface would be as much as sixty inches. Only one other assumption has been found necessary to complete the discussion. In determining the relation between rainfall at Rivas and rise in the lake surface the following method was used. It was found that for the year 1898 one hundred and eight inches (108) of rainfall at Rivas corresponded to a rise in the lake of one hundred and fifty-four (154) inches. This is the only directly observed relation that we have. It is not believed that exactly the same ratio will hold for the different rates of rainfall. Mr. Davis says in Appendix III:

"While we have no conclusive data upon which to estimate the percentage of run-off to rainfall in the basin of Lake Nicaragua, it is well established, as a general rule, that in any given basin the greater the rainfall in a given time the greater the percentage of run-off. So that if the rainfall were increased twenty-one per cent. the run-off should be increased somewhat more. Say twenty-five per cent."

If this assumption be applied to the preceding observations, the following table is obtained showing the rise in Lake Nicaragua, corresponding to different rates of rainfall at Rivas.

30 in. of rainfall at Rivas corresponds to 34 in. rise in lake.
40 in. of rainfall at Rivas corresponds to 48 in. rise in lake.
50 in. of rainfall at Rivas corresponds to 63 in. rise in lake.
60 in. of rainfall at Rivas corresponds to 78 in. rise in lake.
70 in. of rainfall at Rivas corresponds to 93 in. rise in lake.
80 in. of rainfall at Rivas corresponds to 109 in. rise in lake.
90 in. of rainfall at Rivas corresponds to 125 in. rise in lake.
100 in. of rainfall at Rivas corresponds to 141 in. rise in lake.
110 in. of rainfall at Rivas corresponds to 157 in. rise in lake.
120 in. of rainfall at Rivas corresponds to 175 in. rise in lake.
130 in. of rainfall at Rivas corresponds to 192 in. rise in lake.

This table is intended to be used only in comparing the total rainfall of different years. When partial seasons are discussed a special determination is made for each case.

As a preliminary step in the investigation, the amount of water necessary for the use of a canal has been determined as follows: If the business of the canal should be 10,000,000 tons annually and 2000 tons should be passed at each lockage, then 5000 lockages would be required on each side. If the vessels were all going one way 5000 lockfuls of water would be used, which would be the maximum. If going alternately in opposite directions, then 2500 lockfuls would be used, which would be a minimum. If the mean be taken then 3750 lockfuls would be used annually on each side, or 7500 on both sides. With a six-lock system this would amount to 7,341,600,000 cubic feet annually.

Leakage is a more variable quantity, depend-

ing upon the condition of the gates, valves, embankments, etc. It is estimated that the leakage in the Poe Lock at Sault Ste. Marie averages 200 cubic feet per second. If this be taken for the leakage of one lock out of Lake Nicaragua then the total leakage of the two sides would be 12,614,400,000 cubic feet annually.

For the purposes of operating the machinery of the locks, generating lights, etc., it is assumed that sixty horse-power operating half the time will be sufficient for one lock. With a fall of 18.4 feet and a loss of twenty-five per cent. in installation, this will require 1,135,296,000 cubic feet annually. The sum of these three quantities is sufficient to lower the lake level three inches annually. The probable changes in the lake level during the period of least rainfall will first be determined.

From November 1, 1889, to June 1, 1891, a period of nineteen months, the total rainfall at Rivas was 38.39 inches. This, from the preceding table would have raised the lake 45.75 inches. Evaporation would have lowered it ninety-five inches and the needs of the canal would have lowered it 4.75 inches. Therefore, the lake at the end of this period would have been 54 inches lower than at the beginning, even though there had been no outflow. This is the driest period observed, but it is not at all anomalous. From the beginning of December, 1884, to the end of April, 1886, a period of seventeen months, the total rainfall was 37.43 inches, which would raise the lake surface 44.40 inches, while evaporation and the needs of a canal would lower it 89 inches, thus leaving it 44.6 inches lower at the end of the period than at the beginning. Again, from the beginning of November, 1894, to the end of April, 1896, a period of 19 months, the total rainfall was 45.15 inches which would cause the lake to rise 55.72 inches, while evaporation would have lowered it 95 inches and the needs of a canal would have lowered it 4.75 inches more, thus leaving the lake 44 inches lower at the end of the dry period than at the beginning. The recurrence of such dry periods three times in twenty years shows that they are to be expected in the future and should be provided for. The only way in which such provision can be made, is by the temporary storage of water in the lake. If at the beginning of the dry period the lake had been 54 inches higher than necessary for a 30-foot draft, then at the end of the dry period the draft would have been reduced to exactly 30 feet. A fluctuation of 54 inches is, therefore, absolutely necessary to provide for periods of as small rainfall as have occurred in the last 20 years. Since it would be impossible to control the lake within exact limits an additional 18 inches of fluctuation has been arbitrarily added, making the total allowable fluctuation six feet. This fluctuation is necessary in order to maintain a 30-foot draft during dry periods.

The periods of large rainfalls will next be considered.

Between June 18 and October 29, 1898, a period of 132 days, the rainfall at Rivas was 76.36 inches, the lake rose 48.00 inches; the outflow lowered it 32.76 inches and the evaporation on the lake surface lowered it 16.88 inches. Therefore, if there had been no evaporation on the lake or outflow from it, it would have risen 97.64 inches.

Between May 17 and October 27, 1897, a period of 164 days, the rainfall at Rivas was 112.42 inches. This was the period of greatest rainfall shown in the Rivas records since 1879. The amount of fluctuation in the surface of Lake Nicaragua caused by this rainfall was not observed; an attempt will be made to determine

it by comparison with the wet portion of 1898, when both fluctuation and rainfall were carefully measured. The problem may then be briefly stated as follows: If a rainfall of 76.36 inches in 132 days would cause a rise in the lake surface of 97.64 inches, what rise would be caused by a rainfall of 112.42 inches in 164 days? The ratio between rainfall and change in lake level, as given in the preceding table, cannot be used for this problem, because in this case only portions of a season are considered. At the beginning of these periods the streams and marshes were drained, and empty. At the end they were overflowing and the entire run-off due to the rainfall had not yet occurred. Therefore, this problem must be solved as a special case. If the rise was exactly proportional to the rainfall it would be 143.7 inches, provided there was no evaporation on the lake nor outflow from it. It is, however, probable that in this case as in the preceding one, the greater daily rate of rainfall in 1897 would cause the lake to rise slightly more than the proportional amount. An examination shows that the daily rate of rainfall in 1897 was 18 per cent. greater than in 1898. Using the ratio as before, the rise in the lake would be 22 per cent. greater. Applying this per cent. the computed rise in the lake for 1897 would be increased from 143.7 inches to 148.58 inches. This, then, is the estimated amount of fluctuation that would have occurred during the period of greatest rainfall of the last 20 years, if there had been no evaporation on the lake nor outflow from it.

The question as to what amount of fluctuation in the lake will be necessary to take care of this rainfall will next be considered. The estimated rise of 148.58 inches must be provided for by evaporation, outflow and temporary storage in the lake.

Assuming the ratio of evaporation from the lake surface to be the same as in 1898, it would, for the 164 days, amount to 20.97 inches. Subtracting this from 148.58 inches leaves 127.61 that must be provided for by outflow and temporary storage.

The lake has an area of 3000 square miles, a rise in its surface of 127.61 inches would be equivalent to 889,408,618,000 cubic feet. If this should run out of the lake in 164 days, the mean discharge would be 62,769 cubic feet per second and there would be no permanent change in the elevation of the lake surface. If the lake should be permitted to rise one foot, then the mean discharge would be reduced to 56,866 and each additional foot that the lake is allowed to rise will reduce the mean rate of discharge by an equal amount. The following table shows the required rate of discharge for each foot of fluctuation:

No fluctuation	requires	62,800	cubic	feet	of discharge.
1 foot	"	56,900	"	"	"
2 feet	"	51,000	"	"	"
3 "	"	45,100	"	"	"
4 "	"	39,200	"	"	"
5 "	"	33,300	"	"	"

It appears from this table that if a waste-way having a capacity of 33,300 cubic feet per second be provided, the fluctuation in the lake could be limited to five feet for a rainfall as great as any that has occurred in the last twenty years.

Since the canal itself will incidentally provide waste-ways, exceeding this in capacity, it appears that not more than five feet of rise need

be caused by the largest rainfall. Therefore, the range of fluctuation of 6 feet found sufficient for dry periods will also suffice for wet seasons.

This determination of the volume of the largest flood in the last twenty years is believed to be reasonably correct. It is confirmed by a discussion of the flood-plains of the San Juan river. This discussion made by Dr. Hayes, shows that floods as great as the one under consideration probably occur as frequently as once in twenty years, while still greater floods occur at much longer intervals. It is believed, however, that it will be sufficient to control floods equal to the largest that have occurred in the last twenty years, simply providing locks, embankments, etc., with sufficient heights so that when higher floods occur no damage will be done to the canal.

It will be observed that the preceding determination of the probable changes in lake level are based upon the assumption that the average rainfall in the basin of Lake Nicaragua varies as the rainfall at Rivas. In general, the average rainfall in any considerable area does not have as wide a range as the rainfall at a single station within the area. Therefore, the preceding determination of the fluctuation in the level of Lake Nicaragua is more likely to be too large than too small.

Grade.

Under your instructions the grade has been designed so as to give a minimum depth of 30 feet in the canal at all stages of the sea, lake and ocean. For this purpose tide gages were observed at Greytown and Brito for several months. The grade at the bottom of the canal at these points was placed at 30 feet below mean low tide. At Greytown mean low tide is about one-half foot below mean sea level; at Brito it is about four and one-half feet. The precise levels show that the Pacific ocean, during the time our observations were made, was about one foot lower than the Caribbean sea, therefore, the grade at Brito is about five feet lower than at Greytown, and consequently the maximum lift on the west side will be five feet more than on the east side, while the minimum will be three feet less. The upper level of the canal extends from near Buen Retiro on the west side, to near Machuca on the east side.

The upper limit to which the lake will be allowed to rise has been fixed by you at 110 feet above the mean level of the Caribbean sea. The permissible fluctuation has been limited to six feet. Therefore, the lower limit of the lake surface is 104 feet above sea level and the grade of the upper level of the canal is 74 feet above sea level. The grade of the intermediate parts of the canal is determined by the lifts of the locks.

Additional Waste-Ways.

It is proposed to control the lake level between an elevation of 104 feet and 110 feet above sea level by means of dams in the San Juan river. These dams are to be provided with valves and the outflow from the lake will be entirely cut off for a considerable part of each season. It is also proposed to place the material which is excavated from the river in piles along both banks of the river.

There will be four things that will tend to make the floods in the river higher than heretofore. First, the dams in the river will somewhat obstruct the flow by diminishing the slope and velocity. Second, the spoil banks will contract the section and prevent the flood waters from so readily escaping into the adjacent marshes. Third, the water will be retained in the lake by the dams so that at the beginning of

the rainy season the river will be at a much higher stage than formerly. Fourth, the entire outflow from the lake will be precipitated into the river in five or six months instead of the entire year as formerly. On the other hand, the increased cross section of the river caused by the excavation will tend to facilitate the outflow. This is a large factor and it appears (so far as computations can show) sufficient to about offset the preceding four so that the water might all be carried through the San Juan river, with no greater velocity or higher floods than formerly.

The computed effect of all these hypothetical cases is uncertain, and it is possible that the completed canal might have greater floods and velocities than the San Juan river now has. Again it is desirable that the current in a canal shall be as small as possible. Still water is the ideal case. If the upper San Juan is canalized its channel banks will be of sloping earth, submerged, and invisible. Its curves have a proposed minimum radius of 3000 feet. It is evident that strong currents will make navigation difficult and will tend to erode the banks and refill the excavated channel. In order to reduce these objections to a minimum, a waste-way on the west side is proposed.

The conditions are as follows: The estimated maximum outflow from Lake Nicaragua is 50,000 cubic feet per second. The drainage of the valley of the upper San Juan sometimes amounts to 50,000 cubic feet per second, so that the estimated maximum discharge of the San Juan above the San Carlos is 100,000 cubic feet per second. In order to obtain a minimum current in the canalized portion of the river, it is proposed to divert all the drainage of Lake Nicaragua westward to the Pacific. The drainage of the San Juan valley will be taken down the river, though at times of great floods it will be divided into two parts by the dam at Machuca, one-half being temporarily turned back into the lake. In this way the maximum discharge in the river will be reduced to 25,000 cubic feet per second, and the maximum velocity to 1.5 feet per second.

It is proposed to make the waste-way on the west side through the canal for the first ten miles from the lake. The water will then pass out of the canal through controlling works, similar to those in the Chicago drainage canal. After being discharged from the canal the water will pass down to the sea through the channel of the Rio Grande, which will be enlarged and rectified in places.

The ten miles of canal that it is proposed to use for a waste-way will be almost entirely through rock cutting. The sides of the canal will be almost vertical and may be protected by timber fenders. The water from the lake carries practically no sediment. A velocity of five feet per second will neither injure the canal nor materially interfere with navigation. It is proposed to make this ten miles of the canal 200 feet wide with a fall of two feet. This with a velocity of not more than five feet per second will give a mean discharge of 33,000 cubic feet per second which, as already shown, will be sufficient to limit the fluctuations of the lake surface within five feet. The widening of this part of the canal to 200 feet will be a substantial benefit to navigation. If greater floods should occur, there are additional resources in reserve. The discharge through the waste-ways both on the east and west sides could, with some inconvenience to navigation, be temporarily increased and finally, if the lake should rise a little higher than 110 feet above sea level, but little harm would be done.

ESTIMATES.

Estimates of amounts of material and comparative cost of construction have been made for all the routes indicated on the map. The following nomenclature has been directed by you. The several routes on the west side are called variants of the Childs route.

The Maritime Canal Company's route from the lake to Greytown, leaving the river at Ochoa and crossing the Eastern Divide is called the Menocal route. It has one variant.

The route from the lake to the mouth of the San Carlos and then across the country by way of Lake Silico is called the Lull route. There are four variants to this route. The one north of Lake Silico is called Variant I. The one through Lake Silico is called Variant II. The one south of Lake Silico is called Variant III, and the one passing through the Agua Dulce lagoon is called Variant IV.

A number of different forms of construction have been considered. On the east side estimates have been made for different lock systems. Systems of 3, 5, 6, 7 and 8 locks with 1, 2 and 3 dams in the river have been considered. On the west side systems of 3, 4, 5 and 6 locks have been considered.

Unit prices have been derived as follows:

The cost of excavating has been obtained by comparison with the Chicago Drainage Canal. Here the actual average cost was: for cubic yard of rock, 75 cents; for cubic yard of earth, 28 cents. Messrs. L. E. Cooley and Isham Randolph have expressed their opinions that if the work should be repeated, it could be done for 65 cents and 25 cents, respectively. These prices are, therefore, used as a basis of comparison.

If the Nicaragua Canal were located near Chicago and its rock and earth excavation similar in character to that of the Drainage Canal, then its rock and earth could be excavated for 65 cents and 25 cents per cubic yard. Comparing the material in the two localities: The earth in the Nicaragua Canal varies in character from soft rock to diluted silt. In the Chicago Canal, the range is equally as wide. It is believed that the general average in the two localities would prove to be substantially the same. Therefore, it is assumed that, if the Nicaragua Canal were located near Chicago, the average cost of its earth excavation would be 25 cents per cubic yard.

The rock between Lake Nicaragua and the Pacific is shale and sandstone, thinly stratified and much broken. Some pits of considerable depth have been excavated without blasting; the rock has been used for macadamizing the roads. It is believed that a large part of this rock could be excavated with steam shovel without blasting. It is drilled slightly more easily than the Chicago limestone, and is much more brittle. The location of the spoil banks is not quite so favorable as in the Chicago works. These two opposite conditions have been taken as equal, it has, therefore, been assumed that it could be handled for the same price as the Chicago rock. Between Lake Nicaragua and the Caribbean sea the rock is basalt, dacite and sandstone. The sandstone is in such small quantities that it need not be considered. The basalt and dacite are both considerably harder to drill and blast than the Chicago limestone but somewhat easier than granite. Again in the larger cuts the waste material will have to be transported horizontally three or four miles to the dumping ground. For these reasons it is estimated that the cost per yard will be increased 10 cents. Therefore, it is assumed that if the Nicaragua Canal were located near Chicago, the cost of excavating this rock would be 75 cents per cubic yard on the

east side and 65 cents per cubic yard on the west side. So far the data has been reasonably full and exact and the conclusions cannot be much in error.

It yet remains to assign the relative cost of work in the United States and in Central America. This will involve greater uncertainty, for the reason, that there have been no large works in Central America with which comparison can be made, except the Panama Canal, and for many reasons it is believed that comparison with this work would be misleading. There has, however, been some railroad building in all of the Central American States, often in amounts sufficiently large so that the entire labor was brought to the country from the outside, thus making the conditions of labor somewhat similar to those which would obtain if the Nicaragua Canal should be built. An analysis of the cost of several of these roads has been obtained from engineers who built them. In one case a small amount of work under very unfavorable circumstances cost about 100 per cent. more than it would in the United States. In other cases the difference was less than 50 per cent. The range in results was quite wide but all fell between 25 and 100 per cent. in excess of similar work in the United States.

From a consideration of all the data available the following ratios have been assigned:

The rock on both sides and the earth on the west side will cost 50 per cent. more to excavate in Nicaragua than in the United States.

In view of the excessive rainfall, the earth on the east side would cost 75 per cent. more in Nicaragua than in the United States. Applying these ratios to the prices previously obtained, the unit cost of excavation is found to be as follows:

Rock on the east side	$1.12 per cubic yd.
Rock on the west side	.97 " " "
Earth on the east side	.44 " " "
Earth on the west side	.37 " " "

The cost of the locks has been obtained by comparison with those at Sault Ste. Marie. The material estimated for is concrete walls, steel gates, wooden floors and conduits. The strength and dimensions of the parts necessary for the required Nicaragua locks, were first determined by comparison with the locks at Sault Ste. Marie. The unit prices that have actually been paid at the Sault were then applied. Up to this point the data are quite full and the result is believed to be reasonably exact. The excess of cost in Nicaragua over that in the United States is more uncertain. It is assumed to be 33 per cent. It has been taken lower than that for excavation because a large part of lock construction is for material, some of which can be furnished in Nicaragua at only a slight advance over the price in the United States. These added percentages of 75, 50 and 33 are believed to be large enough to cover all contingencies. Therefore, in the following estimates these unit prices have been reduced so that an item of 20 per cent. for contingencies can be added to the total. The two items of excavation and lock building amount to about 80 per cent. of the total cost. These unit prices are, therefore, relatively very important. The remaining unit prices are determined from such information as could be obtained in Nicaragua and the United States. Some of the items are very uncertain, but it is believed that the aggregate will prove to be reasonably correct.

The following are the unit prices used in all the estimates:

PRICES FOR THE EAST SIDE.

Earth excavation (Obtained by adding 50% to Chicago price of 25¢ per cu. yd.)	$ .37	per cu. yd.
Rock excavation (Obtained by adding 10¢ to Chicago price of 65¢ and then adding 24% to the sum.)	.93	" " "
Rock in Greytown breakwater	1.75	" " "
Timber cribs	3.25	" " "
Clay puddle and back-filling, exclusive of cost of excavation	.50	" " "
Concrete in structures, other than locks	8.30	" " "
Concrete in locks	7.23	" " "
Stone pitching, on embankments	2.00	" sq. yd.
Timber in structures	60.00	" M.B.M.
Clearing	75.00	" acre.
Clearing and grubbing	100.00	" "

PRICES FOR WEST SIDE.

Earth excavation (Obtained by adding 24% to Chicago price of 25¢ per cu. yd.)	$ .31	per cu. yd.
Rock excavation (Obtained by adding 24% to Chicago price of 65¢ per cu. yd.)	.81	" " "
Rock in Brito breakwater	1.50	" " "
Timber cribs	3.00	" " "
Clay puddle and back-filling, exclusive of cost of excavation	.50	" " "
Concrete in structures, other than locks	8.30	" " "
Concrete in locks	7.23	" " "
Stone pitching	1.75	" sq. yd.
Timber in structures	60.00	" M.B.M.
Clearing	75.00	" acre.
Clearing and grubbing	100.00	" "

The first estimate is for the Maritime Canal Company's proposed canal.

The location is shown by the dotted lines on Map No. 2, and is exactly the location chosen by the Canal Company. The dimensions are those assigned by the Company. The more important ones are as follows:

Width of canal, in earth 80 to 120, in rock 100, in river 125, in lake 125 to 275. Depth 28 to 30.

The number of locks is 6. The 3 on the east side have lifts of 31, 35 and 40 feet; and the 3 on the west have lifts of 42.5, 42.5 and 30 feet; usable length 650 feet; width 80 feet.

The slopes in rock range between one horizontal to one vertical and one horizontal to five vertical; in earth between six horizontal to one vertical and three horizontal to one vertical.

The total length of the canal from the 7-fathom curve in the Caribbean sea to the 7-fathom curve in the Pacific ocean is 186.56 miles.

Minimum elevation of lake surface 110 feet above mean sea level (Caribbean sea level).

The estimate of cost is made up as follows:

ESTIMATE ON MENOCAL ROUTE AND PLANS.

EASTERN DIVISION.

Excavation earth, cu. yds. 45,731,712, at 37¢	$16,920,733
Excavation rock, cu. yds. 9,278,803, at 93¢	8,629,287
Embankment, Deseado basin	1,304,919
Embankment, San Carlos ridge	261,114
Embankment, San Francisco ridge	4,780,960
Ochoa dam	1,875,071
Three locks	5,154,760
San Francisco and Deseado sluices	1,947,484
San Carlos sluices	879,408
Clearing and grubbing, acres 731.5, at $100	73,150
Clearing, acres 1186, at $75	88,950
Greytown breakwater, etc	1,273,295

Stone pitching, sq. yds. 7680, at $1.67	$12,826
Guard gate	171,708
Railway, Greytown to Ochoa	1,604,200
Telegraph, miles 72, $500	36,000
	$45,013,865

Western Division.

Childs Route.—Variant II.

Excavation earth, cu. yds. 9,928,756, at 31¢	$ 3,077,914
Excavation rock, cu. yds. 10,638,010, at 81¢	8,616,788
Three locks	4,751,897
Waste-way	406,173
Timber piers, cu. yds. 148,410, at $3.08	457,103
Clearing and grubbing, acres 384, at $100	38,400
Clearing, acres 417, at $75	31,275
Railway and telegraph, 18 miles	909,000
Right of way and bridges	160,000
Jetties, cu. yds. 264,369, at $1.50	396,554
Stone pitching, sq. yds. 23,450, at $1.67	39,162
La Flor dam	2,903,804
Guard gates	153,416
Wall at Lock No. 4	241,405
Western Division	$22,182,891

Western Division	$22,182,891
Eastern Division	45,013,865
	$67,196,756
Sanitary and police	1,000,000
Lights and buoys	500,000
	$68,696,756
Superintendence and engineering	4,121,805
	$72,818,561
Contingencies 20%	14,563,712
Grand total	$87,382,273

It is believed that a canal of this kind if constructed would be both inadequate and unstable. The following are some of the deficiencies that should be supplied in order to make it adequate to the present needs of commerce: the draft should be increased from 28 to 30 feet; the foundations of the San Francisco embankment should be carried down to solid earth, 60 feet in some cases; the Ochoa dam should be built of masonry with its foundations on the rock; the width of the channel in the San Juan river should be increased to 300 feet; several cut-offs should be made; the minimum elevation of the surface of Lake Nicaragua should be reduced to 104 feet above mean sea level so as to permit a fluctuation of 6 feet in the surface of the lake; the width of the canal for 10 miles on the west side should be increased to 200 feet, and waste-ways provided; the La Flor dam should be built of masonry with its foundations on the rock, or as an alternative, omitted entirely and a "low level" route substituted; the harbor at Brito should be modified.

Menocal Route.—Variant I.

Under your instructions an estimate has been made with these modifications: This plan is called the Menocal route, Variant I. The route is shown on Map No. 2 and is on the east side, the same as the Canal Company's route, just considered, except some cut-offs in the San Juan river, which both shorten and cheapen it. On the west side the route is the same for the first 10 miles from the lake. It then passes down the south of the valley of the Rio Grande and the La Flor dam is omitted. This route is somewhat similar to the "low level" plan of the Canal Company.

The dimensions are those assigned by the Commission for all routes. The principal ones are as follows: Depth of water in the canal and

locks not less than 30 feet for all stages of sea, lake and ocean. Usable length of locks 620 feet, width of locks, 80 feet. Width of canal at bottom 100 feet in rock cuts; 150 feet between Greytown and East Divide and between Florida lagoon and Ochoa; 200 feet through the San Francisco and Florida lagoons; and 300 feet in the San Juan river with greater widths at the bends. In Lake Nicaragua the width begins at 300 feet and increases to 600 feet at the outer end. On the west side the width is 200 feet from the lake to the first lock, then 150 feet from there to the sea. The minimum elevation of the surface of Lake Nicaragua is fixed at 104 feet and the maximum at 110 feet above sea level. The number of locks on the east side is 3, with lifts of 36.8 feet each. On the west side there are 6 locks with lifts of 19.3 feet each.

The total length of the route between the 7-fathom curves is 185.32 miles. The estimate of cost is made up as follows:

ESTIMATE.

CARIBBEAN SEA TO PACIFIC OCEAN.

EAST SIDE.

Menocal Route.—Variant I.

Three locks.

Small harbor at Greytown.

Summit level base at elevation 74 (Caribbean datum).

Excavation, earth 87,284,170 cu. yds. at 37¢	$32,295,143
Excavation, rock 10,157,152 cu. yds. at 93¢	9,446,151
San Carlos embankment, dry excavation, earth 353,600 cu. yds. at 37¢	130,832
Ochoa dam and controlling works	6,666,700
San Francisco embankment and dam	4,460,000
Three locks, lift 36.82 feet at $2,204,630	6,613,900
Guard gate	172,000
Sluices and weirs, San Francisco and Deseado basins	1,506,000
Clearing and grubbing, 1461 acres at $100	146,100
Clearing 2460 acres at $75	184,500
Greytown breakwater, stone 550,000 cu. yds. at $1.75	962,500
Timber work for cribs and retaining walls	1,000,000
Stone pitching	100,000
Railroad complete, Greytown to Toro rapids	4,125,000
Total, Eastern Division	$67,808,826

WEST SIDE.

Childs Route.—Variant I.

Six-lock system, with summit level 200 feet wide, remainder 150 feet.

Small harbor at Brito.

Excavation, earth 16,063,377 cu. yds. at 31¢	$ 4,979,646
Excavation, rock 22,625,710 cu. yds. at 81¢	18,326,825
6 locks 19.33 feet lift at $1,601,250	9,607,500
1 lock foundation in alluvium	125,000
Guard gate	153,000
Waste-weirs	1,102,300
Timber pier west side lake, 151,000 cu. yds. at $3.08	465,080
Jetties Brito harbor, 144,107 cu. yds. at $1.50	216,160
Clearing and grubbing, 661 acres at $100	66,100
Clearing 1127 acres at $75	84,525
Railroad complete	514,942
Total Western Division	$35,641,078

Total Western Division	$35,641,078
Total Eastern Division	67,808,826
	$103,449,904

Sanitary and police..	1,000,000
Lights and buoys....	500,000
	$104,949,904
Superintendence and Engineering, 6%...	6,296,994
	$111,246,898
Contingencies, 20% ..	22,249,380
Grand total	$133,496,278

Lull Routes.

Lull Route.—Variant I.

An estimate has been made of a route which follows the Lull route for a portion of its course. It has, therefore, been called a Variant of the Lull route. Its location is shown on Map No. 2. Leaving Greytown harbor it passes north of Lake Silico across the delta plain and approaches the San Juan a few miles above the San Juanillo. It then follows along the north side of the San Juan to the mouth of the San Carlos, above which it enters the river. From this point to the lake it follows the river with a few cut-offs which are shown on the map. On the west side the route is the same as Variant I of the Childs route, which has been previously defined. The dimensions are also the same except that the width from Greytown to the mouth of the San Carlos is 150 feet throughout. The number of locks on the east side is 6, with lifts of 18.4 feet.

The number of dams in the San Juan river is 3. The total length of the line between the 7-fathom curves in the Caribbean sea and the Pacific ocean is 189.98 miles. The estimate is made up as follows:

East Side.

Lull Route.—Variant I.

Six-lock system with 3 dams in river (Boca San Carlos, Conchuda and Machuca) passing north of Lake Silico, includes small harbor at Greytown, lake dredging and curve widening on river section. Summit level base at elevation 74 (Caribbean datum).

Excavation, earth 106,441,923 cu. yds. at 37¢.....	$39,383,511
Excavation, rock 6,158,160 cu. yds. at 93¢	5,727,088
Clearing, acres 4100 at $75.....	307,500
Clearing and grubbing, acres 1575 at $100	157,500
Dam masonry, concrete 385,529 cu. yds. at $8.30.....	3,199,890
Dam construction, not masonry....	3,395,430
Four locks, lift 18.4 feet, depth 48.4 feet	6,406,400
Two locks, lift 18.4 feet, depth 53.4 feet	3,414,800
Waste-weirs	450,300
Sheet piling 1,059,800 feet B. M. at $60	63,588
Breakwater 550,000 cu. yds. at $1.75	962,500
Stone pitching, 120,000 sq. yds. at $2.00	240,000
Guard gate	172,000
Cribs, retaining wall.....	1,000,000
Railroad, complete, Greytown to Savalos river	2,701,110
Total Eastern Division.....	$67,581,607

West Side.

Childs Route.—Variant I.

Six-lock system with summit level 200 feet wide and remainder 150 feet. Small harbor at Brito.

Excavation, earth 16,063,377 cu. yds. at 31¢.....	$ 4,979,645
Excavation, rock 22,625,710 cu. yds. at 81¢.....	18,326,825
Six locks, 19.33 feet lift at $1,601,-250	9,607,500

One lock foundation in alluvium..	125,000
Guard gate	153,000
Waste-weirs	1,102,300
Timber pier, west side of lake 151,000 cu. yds. at $3.08.....	465,080
Jetties, Brito harbor, 144,107 cu. yds., stone at $1.50.....	216,160
Clearing and grubbing, 661 acres at $100	66,100
Clearing 1127 acres at $75.....	84,525
Railroad complete	514,942
Total Western Division.....$35,641,078	

Total Western Division.	$35,641,078
Total Eastern Division .	67,581,617
	$103,222,695
Sanitary and police..	1,000,000
Lights and buoys....	500,000
	$104,722,695
Superintendence and engineering, 6%...	6,283,361
	$111,006,056
Contingencies, 20% ..	22,201,211
Grand total $133,207,267	

Estimates have been made of Variants I, II, III and IV of Lull route. These estimates have all started from a common point in the Sarapiqui ridge. The dimensions, number of locks, etc., are the same as for the preceding estimate.

Lull Route.—Variant I.

Estimate of quantities for a 6-lock system on the line passing north of Lake Silico between Greytown and Sarapiqui ridge. Length of line 22.324 miles.

Excavation, earth 23,406,600 cu. yds. at 37¢.....$	8,660,442
Excavation, rock 1,069,500 cu. yds. at 93¢	994,635
Greytown breakwater, stone in place, 550,000 cu. yds. at $1.75.	962,500
Rio Negro waste-weir, dry excavation, clay 410,000 cu. yds. at 37¢.	151,700
Rio Negro waste-weir, masonry, 2770 cu. yds. at $8.30.....	22,991
Lock No. 1, waste-weir, dry excavation, clay 26,000 cu. yds. at 37¢.	9,620
Lock No. 1, waste-weir, masonry, 250 cu. yds. at $8.30.....	2,075
Two locks 18.414 feet lift at $1,577,000	3,154,000
One lock 18.414 feet lift.....	1,675,400
Stone pitching on embankment 120,000 sq. yds. at $2.....	240,000
Clearing, 1500 acres at $75.....	112,500
Grubbing, 750 acres at $100.....	75,000
Piers at Greytown harbor 5500 lin. ft. at $150.....	825,000
Total .....$	16,885,863

Lull Route.—Variant II.

Estimate of quantities for a 6-lock system on the line through Lake Silico between Greytown and Sarapiqui ridge. Length of line 22.068 miles.

Excavation, earth 24,393,700 cu. yds. at 37¢.....$	9,025,669
Excavation, rock 1,368,700 cu. yds. at 93¢	1,272,891
Greytown breakwater, stone in place, 550,000 cu. yds. at $1.75.	962,500
Rio Negro waste-weir, dry excavation, clay 410,000 cu. yds. at 37¢	151,700
Rio Negro waste-weir, masonry, 2770 cu. yds. at $8.30.....	22,991
Lock No. 1, waste-weir, dry excavation, clay 26,000 cu. yds. at 37¢.	9,620
Lock No. 1, waste-weir, masonry, 250 cu. yds. at $8.30.....	2,075
Two locks, lift 18.414 feet at $1,577,000	3,154,000

One lock, lift 18.414 feet	1,675,400
Stone pitching on embankments, 93,300 sq. yds. at $2	186,600
Clearing, 1500 acres at $75	112,500
Grubbing, 750 acres at $100	75,000
Piers at Greytown harbor, 5500 lin. feet at $150	825,000
Total	$17,475,946

Lull Route.—Variant III.

Estimate of quantities for a 6-lock system on the line south of Lake Silico from harbor head to Sarapiqui ridge. Length of line 24.02 miles.

Excavation, earth 26,548,100 cu. yds. at 37¢	$ 9,822,797
Excavation, rock 1,231,800 cu. yds. at 93¢	1,145,574
Harbor head breakwater, stone in place, 550,000 cu. yds. at $1.75	962,500
Rio Negro waste-weir, dry excavation, clay 410,000 cu. yds. at 37¢	151,700
Rio Negro waste-weir, masonry, 2770 cu. yds. at $8.30	22,991
Lock No. 1, waste-weir, dry excavation, clay 26,000 cu. yds. at 37¢	9,620
Lock No. 1, masonry 250 cu. yds. at $8.30	2,075
Two locks, lift 18.414 feet at $1,577,000	3,154,000
One lock, lift 18.414 feet	1,675,400
Stone pitching on embankment 113,000 sq. yds. at $2	226,000
Clearing, 1650 acres at $75	123,750
Grubbing, 825 acres at $100	82,500
Pier at harbor head, 5500 lin. feet at $150	825,000
Total	$18,203,907

Lull Route.—Variant IV.

Estimate of quantities for a 6-lock system on the line from Agua Dulce along the lower San Juan river to Boca Colorado, then across swamp to Sarapiqui ridge. Length of line 24.53 miles.

Excavation, earth 23,095,100 cu. yds. at 37¢	$ 8,545,187
Excavation, rock 570,000 cu. yds. at 93¢	530,100
Agua Dulce breakwater, stone in place 550,000 cu. yds. at $1.75	962,500
Rio Negro waste-weir, dry excavation, clay 410,000 cu. yds. at 37¢.	151,700
Rio Negro waste-weir, masonry, 2770 cu. yds. at $8.30	22,991
Three locks, lift 18.414 feet at $1,675,400	5,026,200
Stone pitching 194,900 sq. yds. at $2	389,800
Clearing, 1240 acres at $75	93,000
Grubbing, 620 acres at $100	62,000
Pier Agua Dulce, 5500 lin. feet at $150	825,000
Total	$16,608,478

If each of these partial routes be combined with the total estimate of the Lull Variant I, the following are obtained:

Lull Route.—Variant I.

Total cost of route north of Silico . $133,207,267
Length 189.98 miles (see page 76).

Lull Route.—Variant II.

Through Silico $133,957,853
Length 189.76 miles.

Lull Route.—Variant III.

South of Silico $134,883,819
Length 191.75 miles.

Lull Route.—Variant IV.

Agua Dulce $132,854,433
Length 192.25 miles.

The route through Agua Dulce is a little the cheapest of the four, but it is two miles longer

and is rejected on that account. The route through Lake Silico is one-quarter of a mile shorter than the northern route, but costs a half a million more. It is therefore rejected. The route south of the lake is longer and more expensive than the northern one, it is therefore rejected and the northern one selected. The small difference in the cost of these various routes shows that choice, so far as cost alone is concerned, is practically immaterial. The northern route has in addition some advantages over the others, for example, it can, without additional cost, be made to enter the sea near Indio river. This may prove desirable. This completes the estimate of the proposed locations.

Locks.

So far, for the purposes of comparison, 6-lock systems have been considered on both the east and west sides.

An attempt will now be made to determine the most desirable number of locks. The east and west sides will be considered separately.

In any system of locks there are some advantages in having the dimensions of all the locks uniform. The lift for each lock in any system has been found by dividing the total lift by the number of locks in the system. The total lift on the east side from low water in the Caribbean sea to high water in Lake Nicaragua being 110.5 feet, the lift of a single lock in a 5-lock system is 22.1 feet; in a 6-lock system 18.4 feet; in a 7-lock system 15.8 feet; and in an 8-lock system 13.8 feet.

The number of dams in the San Juan river is also variable. Systems of 1, 2, and 3 dams have been considered. A single dam at the mouth of the San Carlos river would have a head of 55 feet in ordinary stages of water. In a system of 2 dams, each dam would have a head of 27.5 feet and in a system of 3 dams that head would be 18.4 feet.

Estimates have been made of the cost of 5, 6, 7 and 8-lock systems on the east side, and each one of these has been combined with systems of 2 and 3 dams. The results are as follows:

Estimates.

Lake Nicaragua to Caribbean Sea.

Totals, various systems with one to three dams in river. Passing north of Lake Silico and including small harbor at Greytown, lake dredging and curve widening on river section. Summit level 74 (Caribbean datum).

5-Lock System, 1 dam in river....	$65,852,817
5-Lock System, 2 dams in river...	67,354,539
5-Lock System, 3 dams in river...	Not feasible.
6-Lock System, 1 dam in river....	$63,240,141
6-Lock System, 2 dams in river...	64,812,470
6-Lock System, 3 dams in river...	67,581,619
7-Lock System, 1 dam in river....	62,669,099
7-Lock System, 2 dams in river...	63,818,731
7-Lock System, 3 dams in river...	67,411,672
8-Lock System, 1 dam in river....	66,829,093
8-Lock System, 2 dams in river...	68,780,662
8-Lock System, 3 dams in river...	71,157,210

On the west side the total lift from low water in the Pacific ocean to high water in Lake Nicaragua is 115.5 feet.

In a system of 4 locks the lift for each lock would be 28.9 feet; 5 locks would be 23.1 feet, and 6 locks would be 19.3 feet. Estimate of cost of 4, 5 and 6-lock systems have been made and are as follows:

West Side.

Childs Route.—Variant I.

Four-lock system with summit level 200 feet wide and remainder 150 feet. Small harbor at Brito.

Excavation, earth 16,226,281 cu. yds. at 31¢	$ 5,030,147
Excavation, rock 23,099,488 cu. yds. at 81¢	18,710,585
Four locks, 29 ft. lift at $1,853,145	7,412,580
Guard gate	153,000
Waste-weir	1,102,300
Timber pier, west side of lake, 151,000 cu. yds. at $3.08	465,080
Jetties, Brito harbor, stone 144,107 cu. yds. at $1.50	216,160
Clearing and grubbing, acres 661 at $100	66,100
Clearing, acres 1127 at $75	84,525
Railroad complete	514,942
Total Western Division	$33,755,419

West Side.

Childs Route.—Variant I.

Five-lock system with summit level 200 feet wide and remainder 150 feet. Small harbor at Brito.

Excavation, earth 16,372,379 cu. yds. at 31¢	$ 5,075,623
Excavation, rock 22,923,053 cu. yds. at 81¢	18,567,673
Five locks, 23.2 feet lift at $1,701,900	8,509,500
One lock foundation in alluvium	125,000
Guard gate	153,000
Waste-weirs	1,102,300
Timber piers west side of lake 151,000 cu. yds at $3.08	465,080
Jetties, Brito harbor, stone 144,107 cu. yds. at $1.50	216,160
Clearing and grubbing, acres 661 at $100	66,100
Clearing, acres 1127 at $75	84,525
Railroad complete	514,942
Total Western Division	$34,879,903

West Side.

Childs Route.—Variant I.

Six-lock system with summit level 200 feet wide and remainder 150 feet. Small harbor at Brito.

Excavation, earth 16,063,377 cu. yds. at 31¢	$ 4,979,646
Excavation, rock 22,625,710 cu. yds. at 81¢	18,326,825
Six locks, 19.33 feet lift at $1,601,250	9,607,500
One lock foundation in alluvium	125,000
Guard gate	153,000
Waste-weirs	1,102,300
Timber pier, west side of lake, 151,000 cu. yds. at $3.08	465,080
Jetties, Brito harbor, stone 144,107 cu. yds. at $1.50	216,160
Clearing and grubbing, acres 661 at $100	66,100
Clearing, acres 1127 at $75	84,525
Railroad	514,942
Total Western Division	$35,641,078

This completes the estimates. They are intended to include all the characteristic variants, both in location and construction. It yet remains to point out their relative merits and defects and to select the one which seems most desirable.

The Menocal plan, as has been previously pointed out, is both inadequate and unstable. The variants of this plan, though adequate, are unsafe. For example, one feature of the plan is an artificial lake of nearly 100 square miles in area and 60 feet deep in places and retained by dams and earth embankments having a length of more than 10 miles. A single well-placed charge of dynamite might break through the crest, in which case the whole delta plain of the San Juan river would be inundated. There

might be great loss of life and it is not probable that the canal could be used again in less than three years.

It does not seem advisable to place such tremendous possibilities within easy reach of the malice of an enemy or the caprice of a madman.

The plan of a single dam at the mouth of the San Carlos is open to the same objection, though in a much less degree. In this case an artificial lake is formed having an area of 48 square miles and a maximum depth of 55 feet, much land, both in Costa Rica and Nicaragua, that might become valuable, would be submerged. The cost, however, is about $5,000,000 less than for a system of 3 dams, and this might be deemed sufficient to govern.

The plan of 3 dams in the river practically eliminates the danger from floods that might be caused by the failure of dams, because the pools of impounded water are small in area and have a maximum depth of only 18 feet. If one of these should be suddenly discharged into the river it would cause a temporary rise of only a few feet. The maximum unit pressure on a system of 3 dams is only one-third as great as for a single dam. For these reasons a system of 3 dams is preferred.

With 3 dams in the river a system of 7 locks is slightly cheaper than any other, the difference between it and a 6-lock system is only $170,000.

The cost of operating a lock is estimated at $40,000 annually. This, if capitalized at 4 per cent., would add $1,000,000 to the first cost, which would make the 7-lock system more expensive than the 6.

The 6-lock system with 3 dams in the river, is therefore chosen for the east side.

On the west side three systems of locks have been considered. Their relative costs are as follows:

4 Locks	$33,755,000
5 Locks	34,879,900
6 Locks	35,641,000

The 4-lock system is the cheapest of the three. The lift in each lock is 28.9 feet. This large lift is objectionable. Again its capacity for passing boats is 13 per cent. less than that of the 6-lock system on the east side. It, however, has the advantage of having rock foundations for all its lock sites.

In order to make the systems comparable with each other, the capitalized cost of operating the additional locks should be included. If, then, we add to the 5-lock system $1,000,000, and to the 6-lock system $2,000,000, their cost can be compared with the 4-lock system. This leaves the 4-lock system decidedly the cheaper of the three.

Since it is unlikely that any system of locks would be pushed to its full capacity during the first years of use and also since it is likely that a duplicate system of locks would soon be constructed, the 4-lock system has been chosen for the present.

A canal with one dam in the river, 6 locks on the east side, 4 locks on the west side and small waste-way to the Pacific has been estimated for as follows:

ESTIMATE.

CARIBBEAN SEA TO PACIFIC OCEAN.

6-Lock system east side. 4-Lock system west side.

EAST SIDE.

Lull Route.—Variant I.

Six-lock system, one dam in river (Boca San Carlos) passing north of Lake Silico, includes small harbor at Greytown, lake dredging and curve widening on river section. Summit level 74 (Caribbean datum).

Excavation, earth 102,099,463 cu. yds. at 37¢	$37,776,801
Excavation, rock 5,490,770 cu. yds. at 93¢	5,106,416
Clearing and grubbing, acres 1575 at $100	157,500
Clearing, acres 4100 at $75	307,500
Dam, concrete	4,570,340
Six locks	9,560,400
Waste-weirs	456,386
Sheet piling 3,819,800 ft. B. M. at $60	229,188
Breakwater 550,000 cu. yds. at $1.75	962,500
Stone pitching 120,000 sq. yds. at $2	240,000
Guard gate	172,000
Pier Greytown	1,000,000
Railroad complete, Greytown to Rio Sabalos	2,701,110
Total Eastern Division	$63,240,141

West Side.

Childs Route.—Variant I.

Four-lock system. 150 feet wide throughout. Small harbor at Brito.

Earth excavation 15,500,530 cu. yds. at 31¢	$ 4,805,164
Rock excavation 18,081,334 cu. yds. at 81¢	14,645,881
Four locks, 29 ft. lift, at $1,853,145	7,412,580
Guard gate	153,000
Waste-weirs	1,102,300
Timber piers, west side of lake, 151,000 cu. yds. at $3.08	465,080
Jetties, Brito harbor, stone 144,107 cu. yds. at $1.50	216,160
Clearing and grubbing, acres 661 at $100	66,100
Clearing, acres 1127 at $75	84,525
Railroad complete	514,942
Total Western Division	$29,465,732
Total Eastern Division	63,240,141
	$92,705,873
Sanitary and police	1,000,000
Lights and buoys	500,000
	$94,205,873
Superintendence and engineering, 6%	5,652,352
	$99,858,225
Contingencies, 20%	19,971,645
	$119,829,870

This plan is the cheapest of any that has been considered, but it includes a high dam in the San Juan river and an insufficient waste-way on the west side, therefore, for reasons already given, it is not preferred.

The preferred location and plan of construction are then as follows:

The route on the east side is shown on the map as "Lull Route, Variant I." It passes north of Lake Silico, enters the San Juan river above the mouth of the San Carlos, follows the river with some cut-offs to Lake Nicaragua, crosses the lake to the mouth of the Lajas. On the west side it is shown as "Childs Route, Variant I." It passes up the valley of the Lajas, crosses the Continental Divide, enters the valley of the Rio Grande and follows down its southern side to Brito.

Its construction contemplates harbors at Greytown and Brito with safe entrances, but small interior basins, 6 locks on the east side with 3 dams in the San Juan river, 4 locks on the west side and waste-way to the Pacific with a mean capacity of 33,000 cubic feet per second. The proposed sites of harbors, locks, dams and waste-ways are shown on the map.

It is neither the shortest route nor the cheapest plan, but, for reasons given, it is preferred. Its estimated cost is as follows:

ESTIMATE.

CARIBBEAN SEA TO PACIFIC OCEAN.

6-Lock system east side. 4-Lock system west side.

Lull Route.—Variant I.

Six-lock system with 3 dams in river (Boca San Carlos, Conchuda and Machuca) passing north of Lake Silico, includes small harbor at Greytown, lake dredging and curve widening on river sections. Summit level at elevation 74 (Caribbean datum).

Excavation, earth 106,441,923 cu. yds. at 37¢	$39,383,511
Excavation, rock 6,158,160 cu. yds. at 93¢	5,727,088
Clearing, acres 4100 at $75	307,500
Clearing and grubbing, acres 1575 at $100	157,500
Dam masonry, concrete, cu. yds. 385,529 at $8.30	3,199,890
Dam construction not masonry	3,395,430
Four locks, lift 18.4 ft., depth 48.4 ft.	6,406,400
Two locks, lift 18.4 ft., depth 53.4 ft.	3,414,800
Waste-weirs	450,300
Sheet piling, feet B. M. 1,059,800 at $60 per M.	63,588
Breakwater, cu. yds. 550,000 at $1.75	962,500
Stone pitching, sq. yds. 120,000 at $2	240,000
Guard gate	172,000
Cribs, retaining walls	1,000,000
Railroad complete, Greytown to Sabalos river	2,701,110
Total Eastern Division	$67,581,607

WEST SIDE.

Childs Route.—Variant I.

Four-lock system with summit level 200 feet wide and remainder 150 feet. Small harbor at Brito.

Excavation, earth 16,226,281 cu. yds. at 31¢	$ 5,030,147
Excavation, rock 23,099,488 cu. yds. at 81¢	18,710,585
Four locks, 29 ft. lift at $1,853,145	7,412,580
Guard gate	153,000
Waste-weirs	1,102,300
Timber pier, west side of lake 151,000 cu. yds. at $3.08	465,080
Jetties, Brito harbor, stone 144,107 cu. yds. at $1.50	216,160
Clearing and grubbing, acres 661 at $100	66,100
Clearing, acres 1127 at $75	84,525
Railroad complete	514,942
Total, Western Division	$33,755,419

Total Western Division	$33,755,419
Total Eastern Division	67,581,617
	$101,337,036
Sanitary and police	1,000,000
Lights and buoys	500,000
	$102,837,036
Superintendence and engineering add 6%	6,170,222
	$109,007,258
Contingencies add 20%	21,801,451
Grand total	$130,808,709

There are some additional conditions bearing upon the cost and order of construction that may be considered here.

The assumed dimensions of the canal are

larger in the aggregate than any hitherto proposed. They are supposed to be sufficient for the growing needs of commerce for a term of years, perhaps 20. It is known that large canals, such as St. Mary's Falls, Manchester and Suez, had comparatively little business during the first years of their use. It is safe to assume that if the Nicaragua Canal should be built, its business would be relatively small at first, and that if adequate to do the business for 20 years it would at first have a capacity largely in excess of its needs. It is possible, and even probable, that a canal 100 feet wide in earth and rock cuts, and 150 feet wide in the river, with suitable passing places would do all the business that came to it for the first few years. The widening of the channel could be done when the needs of commerce demanded it and at no greater cost than if done at first. Wooden locks could be used at first; there is even a possibility that they would be better in the end than masonry locks. They would certainly answer for the first set, until duplicate ones were necessary. An estimate has, therefore, been made of a canal with narrow channels and wooden locks. The estimated cost is as follows:

Estimate.

Caribbean Sea to Pacific Ocean.

6-Lock system east side. 4-Lock system west side.

East Side.

Lull Route.—Variant I.

Six-lock system (timber) 3 dams in river (Lower Machuca, Conchuda and Boca San Carlos) passing north of Lake Silico, including small harbor at Greytown and lake dredging. River section 150 feet wide, balance of canal 100 feet. Summit level 74 (Caribbean datum).

Excavation, earth 78,251,986 cu. yds. at 37¢	$28,953,234
Excavation, rock 4,573,027 cu. yds. at 93¢	4,252,914
Clearing, acres 4100 at $75	307,500
Clearing and grubbing, acres 1575 at $100	157,500
Dam, masonry (concrete) 385,529 cu. yds. at $8.30	3,199,890
Dam construction other than masonry	3,395,430
Two locks, depth 53.4 ft., lift 18.4 ft.	2,000,000
Four locks, depth 48.4 ft., lift 18.4 ft.	3,818,824
Waste-weirs	450,286
Sheet piling, ft. B. M. 1,059,800 at $60 per M.	63,588
Breakwater, 550,000 cu. yds. at $1.75	962,500
Stone pitching, 120,000 sq. yds. at $2	240,000
Guard gate	172,000
Piers, Greytown	1,000,000
Railroad, Greytown to Rio Sabalos	2,701,110
Total, Eastern Division	$51,674,776

West Side.

Childs Route.—Variant I.

Four-lock system (timber) summit level 200 feet wide. Remainder of canal 100 feet wide, except at passing points which are 150 feet wide. Small harbor at Brito.

Excavation, earth 14,966,500 cu. yds. at 31¢	$ 4,639,615
Excavation, rock 21,310,967 cu. yds. at 81¢	17,261,883
Four locks, lift 29 ft. at $1,220,000	4,880,000
Lock foundation in alluvium	125,000
Guard gate	153,000
Waste-weirs	1,102,300
Timber pier, west side lake 151,000 cu. yds. at $3.08	465,080

Jetties, Brito harbor, stone 144,107 cu. yds. at $1.50		216,160
Clearing and grubbing, acres 661 at $100		66,100
Clearing, acres 1127 at $75		84,525
Railroad		514,942
Total Western Division		$29,508,605
Total Eastern Division	$51,674,778	
Total Western Division	29,508,605	
	$81,183,383	
Sanitary and police	1,000,000	
Lights and buoys	500,000	
	$82,683,383	
Superintendence and engineering, 6%	4,961,003	
	$87,644,386	
Contingencies, 20%	17,528,877	
Grand total		$105,173,263

This estimate has been made without any change of location or plan. The only dimension that has been changed is the width of the canal. The material in the locks has been changed from concrete to wood.

It is thus possible to so arrange the order of construction that the use of the canal can begin when an expenditure of $105,000,000 has been made. The remaining $25,000,000 of expenditure need not be made until commerce demands it. This order of construction should, in my opinion, be followed.

In preparing this report all available data have been used; its weight upon different points is variable, and an attempt has been made to point this out in the body of the report. It will be given again here in compact form, so that the relative weight and value of the various conclusions may be fully understood.

First the field work is all of good quality, there are no weak or doubtful parts; as far as it professes to go, it is entirely trustworthy. The many difficulties in the way of doing the field work served only to retard its accomplishment, but did not in any way lower its quality. In amount it is sufficient for preliminary estimates. It is not and was not intended to be minute enough for the preparation of specifications and final exact locations. The computation of quantities has been made and checked with the care usual in such work, and the totals are entirely trustworthy. The relative amounts of earth and rock have been derived from a line of borings along the proposed line of the canal. These borings in important places are usually not more than three thousand feet apart. It is believed that the relative amounts as given will not prove to be much in error. The unit prices for excavation and locks have been obtained by comparison with the known cost of the Chicago Drainage Canal and the locks in the St. Mary's Falls Canal.

Up to this point there can be no large error, at least no larger than would enter into the estimates for a second drainage canal near Chicago or an additional lock at Sault Ste. Marie.

The next step is to assign the difference between the cost of work done in the United States and similar work done in Nicaragua. In this, there is a large amount of uncertainty. The Panama Canal is the only similar work in this region. For obvious reasons it cannot be used for comparison. Again, comparison with work in Central America done by native labor would be misleading, for this is sometimes abnormally cheap. Comparisons have been made with such works as are large enough to require imported labor. The results are not accordant, but the following limits seem reasonably certain.

The excess of cost in Central America would not be less than twenty-five per cent. and would not be greater than one hundred per cent. These are wide limits, but the information at present available does not seem to me sufficient to make them any smaller. I have assigned different percentages to different parts of the work for reasons given. In the aggregate it is assumed that the work in Nicaragua will cost about sixty per cent. more than similar work in the United States. This is but little more than an opinion, which may be changed at any time upon better information.

These estimates have been made for the conditions deemed most likely to occur; unlikely conditions, though possible, have not been considered: for example, an exceptionally healthy period, or a period in which the prices of labor and material were below the average, has not been assumed; these would tend to make the cost of the work less. On the other hand a corrupt administration or a season of pestilence would make the cost of the work more, but these possibilities are remote and have not been considered.

The estimates are intended to be the most probable, that is, they are equally likely to be small or large.

I have the honor to transmit herewith, the special reports of Assistant Engineers, C. W. Hayes, A. P. Davis, J. W. G. Walker, F. L. Stuart, H. H. Trundle, Boyd Ehle, S. S. Evans, Stephen Harris, Andrew Onderdonk, and L. Hankins.

Very respectfully,

E. S. WHEELER,

Chief Engineer, Nicaragua Canal Commission.

APPENDIX II

REPORT

ON THE

GEOLOGY AND PHYSIOGRAPHY

OF THE

NICARAGUA CANAL ROUTE

BY

CHARLES WILLARD HAYES.

Geologist, U. S. Geological Survey.

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By F. LESLIE RANSOME
Asst. Geologist, U. S. G. S.

APPENDIX II

MR. E. S. WHEELER, Chief Engineer, Nicaragua Canal Commission, Washington, D. C.

Sir:—I have the honor to submit herewith a report of my work for the Nicaragua Canal Commission, carried on under your direction. In accordance with your letter of instructions, dated December 21, 1897, received at Greytown, Nicaragua, I assumed immediate charge of the geological party. The work of that party included drilling operations as well as a general geologic and physiographic study of the region adjacent to the route of the proposed canal.

PERSONNEL OF THE PARTY.—The following men were assigned to the party under my charge: Ignatius O'Reardon, as general assistant; Harry Spence and Patrick Tierney, as chief drillers; T. J. H. Archambault, Moriz Bernstein, W. E. Herbert, E. F. Fischer, and E. P. Humphrey, as drillers. Mr. Humphrey was detached from the party and ordered to report to Assistant Engineer Walker on the 15th of February, 1898. On the 13th of August George H. Seymour was added to the party, and on September 1, W. A. Smith and A. H. Miller. With the exception stated above, these men remained with the party continuously until the completion of the work, when they were ordered to report to the Commission at Washington and there discharged. Mr. O'Reardon has continued as my assistant in the office.

DRILLING OPERATIONS.—Drilling operations were begun at Ochoa early in January, 1898. Work was continued at this point and on the San Francisco embankment until early in March. The party was then divided; one party, consisting of Messrs. Tierney, Bernstein and Archambault, being sent to the west side, and another, consisting of Messrs. Spence, Herbert and Fischer, beginning work on the upper San Juan river. The work on the west side was done under my immediate direction, while Mr. O'Reardon was left with the river party to make locations and to keep the records. He was later placed in charge of the party. The work on the west side was completed on July 13, and the party was moved back to the east side and began work on the various proposed dam sites on the river. This work was completed about the middle of September, and the work by the river party was completed on the 23d of that month. Messrs. O'Reardon, Spence and Archambault were then ordered to report at headquarters in Washington, and a single party was started at work on the Eastern Divide. This consisted of Mr. Tierney, in charge, with Messrs. Bernstein, Fischer, Herbert, Seymour, Smith and Miller. The Eastern Divide work was completed early in November, and the boring outfit was stored in Greytown, and all members of the party returned to Washington except Bernstein and Seymour, who remained at Greytown subject to your orders. Early in December it was de-

cided to have some additional work done on the site of the proposed dam at Boca San Carlos, and this was placed in charge of Mr. Bernstein. He began work early in January, 1899, and completed it in about a month.

General Geologic Work.—From the date of receiving your letter of instructions until my return to Washington at the end of September, the greater part of my time was devoted to the personal direction of the boring parties. In connection with this, I was able to make a somewhat detailed examination of the surface geology in the region adjacent to the canal route. It was found, however, that from the nature of the country, and especially by reason of the luxuriant vegetation and the depth of rock decay, conclusions derived from a study of the natural rock outcrops were unsatisfactory, and most of the exact data obtained was by means of the drilling operations. Observations were made on the physiography of the region, which not only have considerable scientific interest, but are believed to have a very direct bearing upon the practical engineering problems connected with the construction of the canal. Some examination was made of regions at some distance from the canal route, though less of this was done than desired, and a much further exploration of this portion of the isthmian region might be made with distinct advantage to the solution of problems connected with the canal. In connection with Mr. Davis a nearly complete circuit of the lake was made and the geology of its shores examined. The region to the northwest of Lakes Nicaragua and Managua was studied with special reference to the origin of those lakes, and also with reference to the practicability of constructing a waste-way from the lake westward to the Pacific.

Scope of the Report.—The accompanying report consists of two parts. The first is in the main theoretical. It embraces some account of the topography of the region, the climatic conditions in their relation to physiographic processes now going on, a description of the various rock formations, a consideration of the seismic phenomena of the region, and the probability of the occurrence of earthquakes and finally a brief outline of the recent geologic history of the region. The second part is a more direct practical application of the facts of geology to the engineering problems. In this the classification of materials is discussed and a somewhat fuller description of the rock formations and their mode of weathering is given, and second, the various localities at which it is intended to erect structures, such as dams, weirs and locks, are described; also the various lines in excavation and the various embankment lines. Not the least important feature of this portion of the report is the discrimination between that which is actually known concerning the geological conditions prevailing at various points and that which is inferred. This naturally leads to the final section of the report, in which the additional work needed before final plans can be made, is pointed out in some detail.

Very respectfully submitted,

C. Willard Hayes,
Geologist, U. S. G. S.

April 12, 1899.

PART I

PHYSIOGRAPHY AND GEOLOGY OF THE CANAL REGION

TOPOGRAPHY.

The Nicaraguan Depression.—The region whose topography has a direct bearing upon the problem of the Nicaragua Canal embraces northern Costa Rica and southern Nicaragua. It is sharply limited on the south by the high volcanic range of Costa Rica which rears its massive form diagonally across the isthmus. It is less definitely limited on the north by the increasing height of a deeply dissected plateau which merges with the high mountains of northern Nicaragua. Between these limits lies a broad irregular depression which extends very nearly across the isthmus in a diagonal direction parallel with the Costa Rican range. This depression is now occupied chiefly by Atlantic drainage, the Continental Divide lying within a short distance of the Pacific. It contains the basins of Lakes Nicaragua and Managua and their outlet, the San Juan river, the latter occupying a position toward its northern margin. It is important to note at the outset that the depression is not a simple river valley. The portion with which we are chiefly concerned, that lying between the lake and the Caribbean, embraces two distinct drainage basins whose streams formerly flowed in opposite directions, although by a geologically recent reversal of the drainage they now have a single outlet to the sea.

Classification of Topographic Features.—When examined in detail the surface of the Nicaraguan depression presents considerable relief and its topographic features naturally group themselves in three classes.

Extending from the base of the Costa Rican volcanoes northward to the San Juan river and beyond are many hills whose summits reach to a tolerably uniform elevation on north and south lines but increase in height from either side of the isthmus toward its axis. In the vicinity of the larger streams as the San Juan and San Carlos these hills have steep slopes and rounded summits. Farther back from the streams the valleys which separate them are narrower and there are considerable areas of level or undulating surface at an altitude corresponding with the hill tops near the streams. It is evident that if the valleys were filled even with the summits of these hills there would be formed a broad undulating plain, sloping gradually up from either side toward the axis of the isthmus. It is entirely probable that such a plain once existed and that it has been converted into a series of even-topped hills and ridges by the cutting of stream channels below its surface. The manner in which this plain was originally formed is manifestly by the long-continued action of streams when the land stood considerably lower

than now, that is, by the process of stream degradation or base leveling. It was, therefore, a gradational and not a constructional plain. If it were reconstructed by the filling of the stream valleys its present altitude would vary between 100 and 200 feet.

As indicated above, numerous valleys now intersect the surface of this old plain. They vary with the size of the streams except in the case of the San Juan. The reasons for this exception will be pointed out later. They are broadest near the large streams where the old plain is nearly or quite destroyed and grow narrower with increasing distance from the main drainage lines. The smaller streams generally head in narrow gorges, but in some cases they have not completely dissected the old plain, flowing upon its surface in shallow valleys which lower down give way to narrow gorges and these in turn to the rather wide alluvial valleys near the trunk stream. The greater part of the erosion which has dissected the surface of the old plain was accomplished when the latter stood much higher than at present. The valleys were then much deeper, and none had extensive flood-plains except perhaps the largest streams near the sea. A recent change in the altitude of the land has brought the valleys below sea level, changing the rivers, at least in their lower portions, from corrading to aggrading streams. They have since silted up the estuaries thus formed, producing the wide alluvial plains through which they now meander.

Corresponding in some degree with the valleys incised within the old plain are eminences rising distinctly above its surface. These are residual hills which by reason of the harder rocks of which they are composed, or their position on the divides, far from the main drainage lines, were never reduced to the level of the plain. Where the plain was best developed, that is near the sea margin on either side, these residual hills are infrequent and inconspicuous. Thus to the southward of the San Juan, in the region lying between the Sarapiqui and the San Carlos, there is an extensive area in which the hills are almost wholly remnants of the dissected plain, their summits in general presenting little variation in altitude. To the northward of the San Juan the residual hills occur with increasing frequency and greater altitude, and finally merge with the mountains of northern Nicaragua. It is only where the old plain is somewhat well preserved that the true character of the residual hills is clearly seen. At certain points along the San Juan they rise directly from the river valley, all remnants of the intermediate plain having been destroyed. The residual hills also increase in number and height from either side of the isthmus toward its center, being most abundant along a line which crosses the San Juan valley in the vicinity of Castillo. If the plain were reconstructed by the filling of the valleys it would not be continuous but would pass from one side of the isthmus to the other through comparatively low gaps between the residual hills.

Summing up the above statements very briefly, then, it appears that we have in this region a broadly undulating plain formed by the erosion of streams flowing to the Pacific and to the Atlantic from low gaps at the Divide. Above this plain are residual hills, most abundant at the axis of the isthmus where the Continental Divide was formerly located, but increasing toward the north where they merge with the mountains of northern Nicaragua; and, finally, there are many valleys cut in the surface of the plain by the erosion of the streams after the region had been lifted to a higher altitude.

The lower portions of these valleys have subsequently been drowned and silted up, with the formation of broad alluvial flood-plains.

With these fundamental conceptions clearly in mind the topographic features of the Nicaraguan depression may be taken up and described more in detail. They will be considered in the reverse order, that is, the youngest of the topographic forms will be considered first and the successively older ones later.

Alluvial Plains.—Since the river valleys are in general closely followed by canal routes the alluvial flood-plains become of prime importance in planning any canal. They should be considered not alone with reference to their present form and composition, but also, in this region at least, with reference to their origin and the topographic forms which they cover and conceal.

The coastal plain on the Atlantic side of the isthmus increases from a mere fringe at the base of the mountains in Costa Rica northward to a belt from 10 to 15 miles wide in the vicinity of Greytown. This portion of it is formed chiefly from materials brought down by the rivers heading in the Costa Rican volcanoes; it is, in fact, a series of coalescing deltas of which the largest is that formed by the San Juan. The sediment brought down to the sea by streams north of the San Juan is very small compared with that brought down by those to the south. The more rapidly growing southern deltas would, therefore, be extended seaward except for a strong northward littoral sand current set up by the oblique direction at which the prevailing winds strike the shore. The true littoral current in this portion of the Caribbean is to the southward, but its capacity for transporting sediment is more than neutralized by the active northward sand drift within the zone of surf action. This sand drift tends to distribute the sediment evenly along the coast and preserve gently curving coast lines. Notwithstanding this tendency the San Juan delta has been built out a short distance into the Caribbean forming a shallow embayment to the northward of Harbor Head.

The level surface of the delta plain is interrupted by numerous low rounded hills composed of residual clay derived from the decay of rock in situ, and differing decidedly in appearance and composition from the surrounding alluvium. These hills have the form and appearance of islands rising above the level delta plain, and it is quite probable that they were at one time islands fringing the shore before the alluvial deposits extended out to them and connected them with the mainland.

The inner margin of the delta plain is extremely irregular. The isolated hills increase in number and size and finally merge with the dissected interior highland while the delta plain itself merges with the broad flood-plains of the streams.

The surface of the delta plain in its seaward portion is but a few feet above tide level. Its extreme outer margin is marked by low ridges parallel with the shore, formed by the sand thrown up during exceptional storms. From the shore margin the surface of the plain ascends towards the interior at a fairly uniform rate of about 18 inches to the mile.

The surface of the delta plain is also diversified by numerous small lakes and lagoons. These are produced chiefly in two ways: (1) by the formation of sand spits and, (2) by unequal sedimentation.

Sediment is delivered by the larger streams slightly faster than it can be distributed by the littoral current. Hence it tends to build out a delta, but this is deflected in the direction of

the current and forms a curved sand spit which for a time makes a well-sheltered harbor. As the sand spit continues to grow, however, its point eventually joins the mainland and the harbor is converted into a closed lagoon. This complete cycle of changes has taken place at Greytown during the last century and a half. The cycle has also been repeated at the same point several times previous to the last, giving rise to the Shepard, Sucio, Barca and Ibo lagoons which occur back of and parallel with the one last formed. (See Plate I.)

Agua Dulce and Parada lagoons doubtless owe their origin to the same process. The mouth of the stream emptying into the lagoon is for a time carried forward in the direction of the littoral current, but when this has gone to a certain point, the river seeks a more direct course to the sea, breaking through the barrier as the Colorado has evidently done very recently while the deserted outlet is quickly obliterated. The lagoons are thus arranged in parallel series on that side of the stream toward which the littoral current sets. The position of the Agua Dulce and Parada lagoons with reference to the Colorado river therefore proves conclusively that the northward sand current observed opposite Greytown originates to the southward, at least beyond the Colorado.

The second method by which lagoons are formed on the delta plain is by unequal sedimentation. As the coast was built outward by additions to its outer margin it advanced past numerous islands which had fringed the shore. These in some cases prevented the uniform deposition of sediment by interrupting the littoral sand stream and the areas in which little or no deposition took place subsequently formed lakes. Perhaps the best example of a lake formed in this manner is Lake Silico. This occupies what was evidently at one time a bay sheltered by the Silico hills which then formed a group of islands. As the delta plain was built out connecting these islands with the mainland the sheltered bay was not filled by sediment, but its opening was cut off and a lake thus formed.

Another class of lakes or lagoons formed by unequal sedimentation is found about the margins of the delta plain and of the river flood-plains. The rivers which head upon the Costa Rican volcanoes carry a much more abundant supply of sediment than the smaller streams which flow from a region composed of compact residual clays protected by a heavy mantle of vegetation. Hence the flood-plains of the San Juan, below the confluence with the San Carlos, are built up more rapidly than those of its tributaries. The latter are therefore dammed and form lagoons in their upper basins. The Florida lagoon is a typical example of this class. Since they occupy drowned stream basins in a region which originally had considerable relief, their outlines are very irregular, the water backing up all the minor tributaries of the basin. In some cases, as in the Tamborcito region, the water surface has been raised above the gaps between neighboring streams and their basins are now confluent while the residual land rising above the lagoon level forms isolated groups of hills.

The lagoons of the delta plain formed in these various ways are at first open lakes, but they gradually become choked by vegetation and filled with fine silt so that they are converted into grassy marshes and finally when the silt becomes sufficiently consolidated to form a stable support the forest trees encroach upon the marsh and all trace of the lagoon is lost. Numerous examples occur in the delta plains, illus-

MAP OF THE SAN JUAN DELTA.

trating every step in the process: first, the open lagoon, then the floating grass-mat, then the Silico swamp, and finally the heavy forest.

As already indicated, the delta-plain at its inner margin merges with the broad flood-plain of the San Juan river and any line separating the two would be purely arbitrary. For convenience, however, the head of the delta may be placed at the point where the first distributary, the San Juanillo, leaves the main stream.

Most flood-plains are formed by the lateral cutting of streams as they swing from side to side in their valleys. A plain thus cut in the underlying rocks is usually covered with a thin sheet of alluvial material. The flood-plains of this region, however, belong to a totally different class. They include no level plains cut in the underlying rock or residual material which covers the rock. On the other hand, the alluvium has very considerable depth, and instead of forming a layer of uniform thickness, fills a series of old stream channels. It is evident that these channels were formed when the land stood higher than now, for many of them extend below sea level. There is thus an old land surface concealed beneath the alluvial deposits, and a consideration of its topography becomes a matter of prime importance to the engineer. This buried topography will be considered more fully in connection with the unburied portion of the same surface, that is, the surface of the hills rising above the margins of the alluvial plains.

Extensive flood-plains extend up the San Juan river to the mouth of the San Carlos; above this to the head of the Toro rapids the river flows in a comparatively narrow gorge and its flood-plains are narrow and inconspicuous. From the Boca San Carlos downward to the head of the delta, flood-plains are always present on one or both sides of the river, though they are most extensively developed on the south side. The surface is slightly higher near the river, forming the natural levee which characterizes most flood-plains. The outer margins are depressed and occupied by swamps or lagoons. The surface of the flood-plains in the vicinity of the Boca San Carlos varies from 15 to 20 feet above the river at ordinary low stages. As the plains become more extensive downstream, their surface is slightly less elevated, since the floods which deposit the alluvium, having opportunity to spread over a much larger area, do not rise so high.

The slope of the flood-plains from the Boca San Carlos to the head of the delta is about 12 inches per mile. This slope is dependent upon the volume of the river and the character and quantity of the sediment which it carries. It is therefore much steeper below the mouth of the San Carlos than above, for it is from this stream that the greater part of the coarse sediment in the lower river is derived, but it is only about two-thirds as great as the slope of the delta plain.

As stated above, the flood-plains are inconspicuous from the Boca San Carlos to the head of the Toro rapids. The river flows in a comparatively narrow gorge and is generally bordered by rather steep hills which approach nearly to the river channel. At the head of the Toro rapids, however, the valley widens, and from this point to the lake the river is everywhere bordered on one or both sides by extensive flood-plains. Although their general relations to the river are similar to those bordering its lower course they yet differ in some important particulars. They have been formed by sediment borne, not by the river itself, but by tributaries coming into the valley on either side. They thus have the form of coalescing deltas. The

natural levee which is a conspicuous feature in the flood-plains of the lower river is absent, and the plains generally show a gradual descent from their outer margins toward the river. Hence there are no lagoons upon the tributaries such as are found on the tributaries of the lower river, and the flood-plain becomes gradually firmer and more heavily wooded with increasing distance from the river. From the mode of formation of these plains it is manifest that the river is in a stable position and does not show that tendency to seek a new channel which is characteristic of delta streams.

Most of the streams entering Lake Nicaragua on its northeastern side at one time entered the heads of estuaries. These estuaries have been almost entirely filled with alluvial deposits, and in some cases somewhat extensive deltas have been built out into the lake. The absence of a surf in this portion of the lake, except on rare occasions, owing to the direction of prevailing winds, permits the building of deltas which carry the distributaries of the streams a considerable distance out from the general shore line. The most extensive alluvial deposits about the lake are at its southern end. This portion of the lake basin appears to have been originally rather shallow and the sediment brought in by streams from the south, notably by the Rio Frio, has considerably contracted its area. The newly-added land forms about the margin of the lake an extensive swamp through which the streams meander in a network of interlacing distributaries, all more or less obstructed by vegetation. The land becomes gradually firmer at increasing distances from the lake and finally passes into an ordinary alluvial flood-plain. Streams entering the lake from the southwest in general flow in channels which were at one time excavated to a very inconsiderable depth below the present surface of the plain through which they flowed. This plain, it may be remarked in passing, is not alluvial, but is a plain of degradation. Hence these streams are bordered by very inconsiderable alluvial plains and that only near the lake. The streams entering the Pacific from this portion of the isthmus are all short and consequently small, since the Continental Divide is near the west coast. They occupy valleys which have been cut to a much greater depth than they have at present, and these old valleys have been recently drowned and more or less perfectly filled with alluvial deposits. Where the filling is not quite complete an estuary occupies the old river valley and forms a harbor as in the case at San Juan del Sur. Where the filling is complete, as in the valley of the Rio Grande, the headlands which mark the margins of the former deep valley are connected by a curved beach which does not indent the coast to any appreciable extent. The depth of the alluvium in the Rio Grande valley varies from about 40 feet at the head of the flood-plain to something over 100 feet at the coast. The stream which has filled this valley carries at certain seasons an abundant supply of sediment, so that the seaward slope of the flood-plain is rather steep, a little over ten feet to the mile. The conditions in this region which determine the rate of erosion are much more favorable to rapid degradation of the surface than in the region of much greater rainfall to the east, where the rain is distributed somewhat equally throughout the year. The streams are alternately shrunken to mere rivulets and swelled to torrents and the resulting flood-plain has somewhat the character of an alluvial cone.

The Dissected Peneplain.—The group of topographic forms to be described next in order after the alluvial plains, consists of a more or

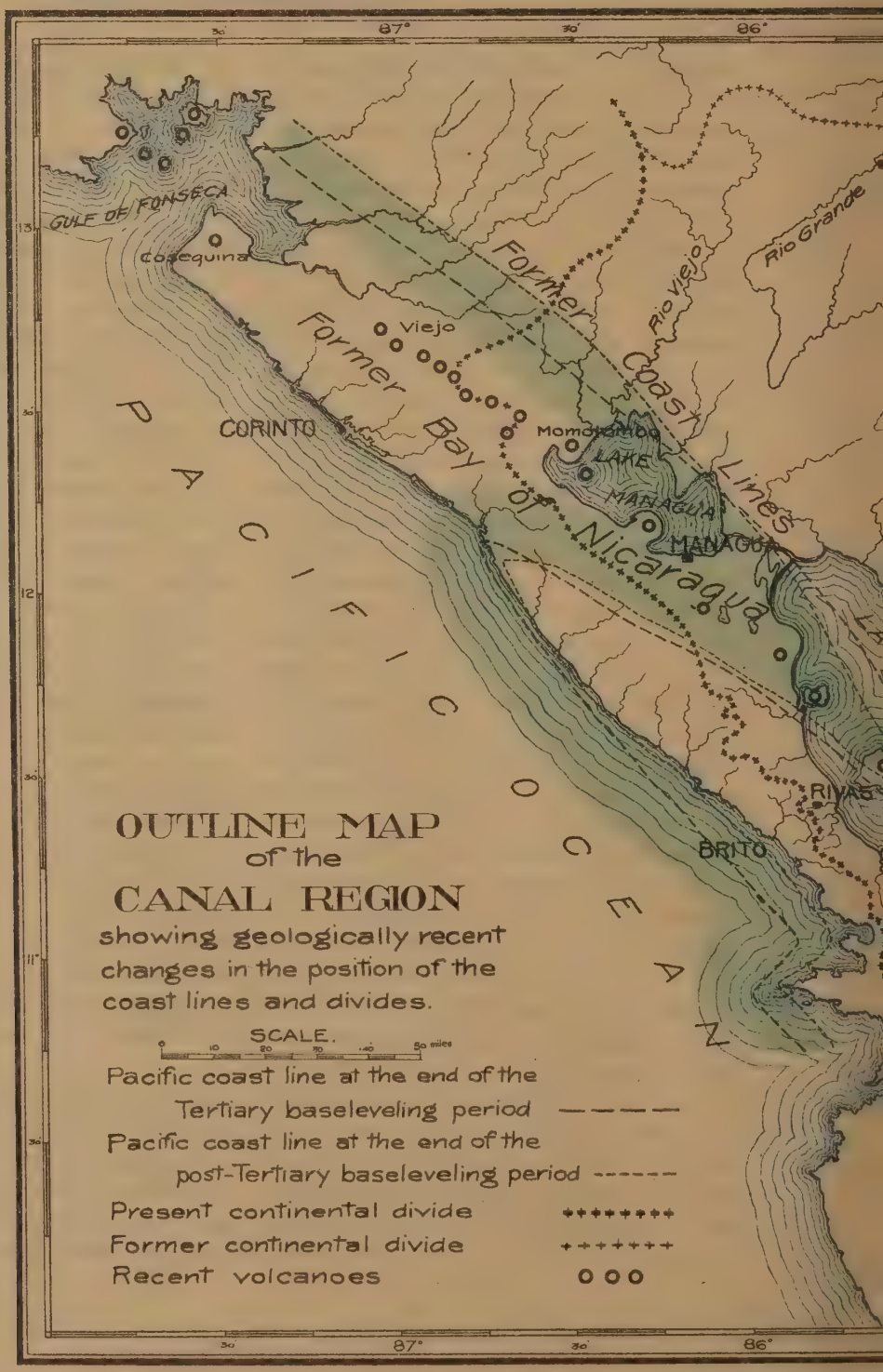
less completely dissected plain or peneplain of degradation. In order to understand the present topography it is necessary to consider the original form of this plain and the manner in which it was developed. The conditions which prevailed prior to its formation cannot be definitely determined, but may be inferred in a general way. There was probably a somewhat elevated plateau growing broader and higher both to the northward and the southward from a somewhat constricted region now occupied by the Nicaraguan depression. The Continental Divide at that time probably occupied a position near the central part of the isthmus, crossing the present San Juan valley in the vicinity of the Castillo rapids, and streams heading upon this Divide flowed to the seas on either side. Another important difference was in the form and position of the Pacific coast line. The differences in the geography of the region, so far as they can be inferred, are represented on the accompanying sketch map, Plate II. It will be noted that Lake Nicaragua did not then exist. Its present basin was occupied in part by a bay indenting the coast line and in part by the basins of rivers tributary to this bay. The region occupied by the volcanic peaks of the Nicaraguan range and the volcanic plateau west of the lake was then occupied by the sea. A cape projecting northward between the sea and the bay was composed of low hills now forming the Continental Divide southwest of the lake.

In still other respects the drainage of the region during the formation of this peneplain differed from the present. The San Juan river receives only small tributaries from the north while it receives both small and large from the south. The large tributaries include the Frio, Poco Sol, San Carlos and Sarapiqui. These all head upon the slopes of the Costa Rican volcanic range which forms the southern margin of the Nicaraguan depression. The upper portions of these streams are normal to the mountain range, the axes of their valleys being at right angles to the axis of the range and also to the general course of the San Juan. Midway of their courses, however, there is an abrupt change in direction. The Frio and Poco Sol bend westward while the San Carlos and Sarapiqui bend eastward, the axes of the lower valleys in every case making a rather acute angle with the course of the San Juan. It seems probable that when the peneplain was being developed in this region the two rivers whose basins now form that of the San Juan occupied the axes of those basins receiving tributaries of equal length from either side. The volcanic eruptions to the south, however, obliterated the former drainage of that region, and the *consequent* streams developed on the flanks of the newly-formed mountains were turned northward, discharging into the heads of the pre-existing small tributaries. It thus appears that the four above-named southern tributaries of the San Juan have composite courses. Their upper courses, normal to the trunk stream, are consequent upon the constructional slope of the recent volcanic range, their lower courses making acute angles with the trunk stream are inherited from the normally-developed, small tributaries of two streams flowing east and west.

The rapidity with which the streams heading upon the Continental Divide reduced their valleys to base level depended chiefly upon the character of the rocks which they encountered, while the rate at which the Divide was lowered by the action of opposing streams depended upon the character of the rocks and the distance of the Divide from the coast, or the width of the isthmus. The region to the northward is probably occupied by older and more resistant rocks,

including gneisses, schists and quartzites. Of that to the south very little is known since its topography has been entirely changed and its older rock formations concealed by the recent eruptions of its volcanoes. From this combination of circumstances it followed that the surface was most completely degraded and the Divide most rapidly lowered along a belt extending diagonally across the isthmus and now forming the great Nicaraguan depression. A broad river basin was developed on the east side of the Divide, occupying the present position of the lower San Juan basin. The land between its various southern tributaries was reduced to low relief. Its northern tributaries were separated by somewhat higher hills, probably the result chiefly of the greater original elevation of this portion of the region. Another river system developed a similar basin with its outlet to the west. The several upper tributaries of each of these two river systems headed upon the Continental Divide in low gaps against the tributaries of the other system. The basin of the western system was somewhat larger than the one on the east of the Divide. Its lower portion was separated from the Pacific by a range of hills which continued northwestward, forming the cape between the then existing bay and the ocean. The southern portion of the present basin of Lake Nicaragua was occupied by this river system, and extensive plains were developed on either side of the axis extending up the tributaries as broad valleys well back into the surrounding hills.

The foregoing brief account of the original extent of this peneplain and the manner in which it was formed is an essential preliminary to an understanding of the present topography of the region. At the conclusion of the long period of degradation, during which the Nicaraguan depression was reduced to a region of low relief, the land was slowly elevated until it stood some hundred feet higher than before and perhaps two hundred feet higher than now. The elevation stimulated the streams to renewed activity, and they began trenching the valleys which they had previously formed. The erosion was at first most active near the coast and worked backward toward the interior most rapidly along the largest streams. The portions of the peneplain most completely dissected were, therefore, its outer margins. Here the surface was almost entirely reduced to the lower base-level and only a few rounded hills on the divides retained any trace of the former plain. The first of these remnants seen on ascending the San Juan are in the vicinity of the delta head where low hills approach the river on the north side. This region, however, has been so deeply dissected that the hilltops scarcely suggest the existence of a former plain. Other hills of similar character occur along the river, chiefly on the north side, although the most prominent hills which come down to the river do not belong to the group now being described but to the residual hills which rose above the surface of the old plain at the time of its most perfect development. The remnants of the dissected plain increase in number and in the regularity of their summits until in the vicinity of Ochoa their uniformity is such that the position of the old peneplain can be accurately determined. The dense tropical forests mask the minor topographic features so that the uniformity in the summits of the hills is not at once apparent. The detailed contour maps, however, of those portions of the region which have been actually surveyed exhibit the uniformity in a striking manner. The present elevation of the hilltops in this region is about 150 feet above sea level, and the



MAP SHOWING CHANGE

AST LINES AND DIVIDES.

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LITHOGRAPHERS
BALTIMORE, MD

uniformity of their summits is shown in the sections of the San Carlos embankment line, Fig. 2, Plate III. To the south of the river the old plain was very extensively developed, and while it has suffered much subsequent dissection, there is a large area in which its former position can be readily determined by the summits of the present hills. To the north of the river it was less extensive, forming only broad valleys between the residual hills which occupied the divides. Although not so extensively developed here as south of the river, the plain has been somewhat better preserved and many streams are found which have not yet lowered their valleys appreciably below the old surface. Heading upon the steep residual hills their upper courses are in sharply cut V-shaped valleys. Emerging from these they flow in shallow valleys across the remnant of the old plain, their channels meandering and obstructed by swamps. Farther down they enter narrow gorges which they have cut and are still deepening in the old peneplain. Still farther down they are bordered by alluvial plains where the valleys which they cut in the old plain have been depressed below base level and so silted up.

These features are admirably shown on the Machado and other tributaries of the San Juan in the vicinity of Ochoa. They may perhaps be made clearer by reference to the somewhat idealized sketch and section forming Fig. 1, Plate III. The surface of the peneplain is indicated by the even summits of the hills to the right. Residual hills are represented to the left, rising abruptly and distinctly above the surface of the peneplain. The profile shows a transverse section of the San Juan valley and a longitudinal section of the valley of a tributary stream. The latter is represented as rising in the residual hills to the left and flowing for some distance in the narrow gorge *a b*. From *b* to *c* the stream flows in a broad, shallow valley at about the level of the peneplain. From *c* to *d* it is in a narrow gorge recently cut and still being actively deepened within the peneplain. It emerges from this gorge at *d* and thence to the margin of the main river valley at *e* it meanders through an alluvial plain, the continuation of the San Juan flood-plain *e f*. The bottom of the valleys which the tributary and the trunk stream occupied before the recent depression of the region is represented in the profile by the solid line between the alluvium and the underlying rock. When these valleys were formed they were considerably above sea level and the streams had a much more rapid fall than at present, but they are now somewhat below sea level.

Continuing westward from Ochoa the summits of the hills become less uniform in altitude, corresponding with the originally less perfect development of the old peneplain in the vicinity of the former Continental Divide. Along the upper portion of the river, west of the Toro rapids, are numerous low, rounded hills merging on either side of the valley with a more continuous upland and these probably mark the position of the former peneplain. It slopes gently westward and probably passes beneath the waters of Lake Nicaragua. The broad valleys bordering the streams which enter the northeastern side of the lake and the level plain which forms the western margin of the lake basin probably constitute parts of this old plain, which have here almost entirely escaped dissection.

In connection with the remnants of this old peneplain the topography of the surface now concealed by the alluvial deposits should be considered. At the close of the period of high level, during which the plain was dissected, the

valleys were rather narrow with steep slopes except near the coast. If the subsidence which inaugurated the period of alluviation had occurred all at once, tidewater would have extended up the valley of the San Juan beyond the Boca San Carlos and also some distance up its tributaries. It is probable, however, that the land sank very slowly so that the estuaries were never deep, but were filled by alluvium almost as fast as formed. The depth of these old valleys having been determined by borings at various points on the trunk stream and some of its tributaries, it is possible to reconstruct the former surface and determine approximately the depth of the alluvial filling in any part of the drainage system. It is found that the erosion of the hills has been inconsiderable since the submergence, for the slopes above the margin of the flood-plains are practically the same as the old slope beneath the alluvial cover. The forms of the alluvium-filled valleys are shown on the sections representing portions of the San Francisco embankment line, Plate XVIII. The valleys of the lower San Juan and its tributaries have been filled in such a manner that the present streams follow very nearly the same course as the streams which formed the valleys. In some cases their meanders have carried them to one side or the other of the old valley where they are now cutting against the bordering hills of residual clay.

While the existence of this old channel might be inferred with certainty from a study of the present river valley, its form and seaward gradient could be determined only by boring. From the data obtained with the drill at the various dam sites and other points on the river between Machuca and Tambor Grande, transverse and longitudinal sections have been constructed, which show fairly well the characteristics of the buried channel. Its gradient as shown on the longitudinal section, Fig. 2, Plate XV, is fairly uniform but considerably steeper, than the gradient of the present river. The lower portion is also steeper than the upper. Thus from Castillo to Ochoa the gradient of the rock channel is about 3 feet per mile, while from Ochoa to Tambor Grande it is 5.8 feet. The minor irregularities in the channel are doubtless due to differences in the hardness of the rocks, but the increased slope of the lower portion of the channel is probably due to some change in conditions during its formation, such as a slight uplift toward the end of the gorge-cutting period. The form of the buried channel is shown on the five transverse sections at dam sites between Machuca and Tambor Grande, Figs. 3 to 7, Plate XVII. In general the buried slopes conform with those above the present river, and its flood-plains and the sections are about what would have been inferred from the exposed slopes.

The original form of the surface concealed by the flood-plain of the upper San Juan is much more difficult to make out. This plain was formed by deposition in quiet water, the river valley being entirely drowned. Hence the present channel was not determined by the deepest portion of the old valley but by the relative amounts of sediment brought into this portion of the lake by tributaries on either side. It is evident that the stream bearing the largest amount of sediment is the Rio Frio, and the delta of this stream has pushed the outlet of the lake northward away from the deeper portion of the old valley and against the hills which formed its margin. The same thing is seen at various points between the lake and the Toro rapids. At numerous points the meanders of the river carry it away from the deeper portions

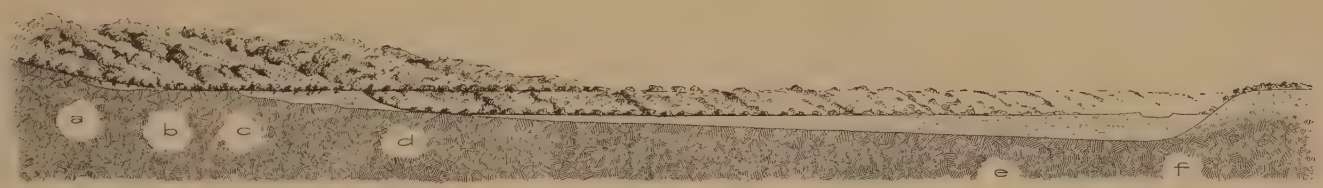


Fig 1
Idealized sketch and section illustrating certain topographic features of the San Juan valley.

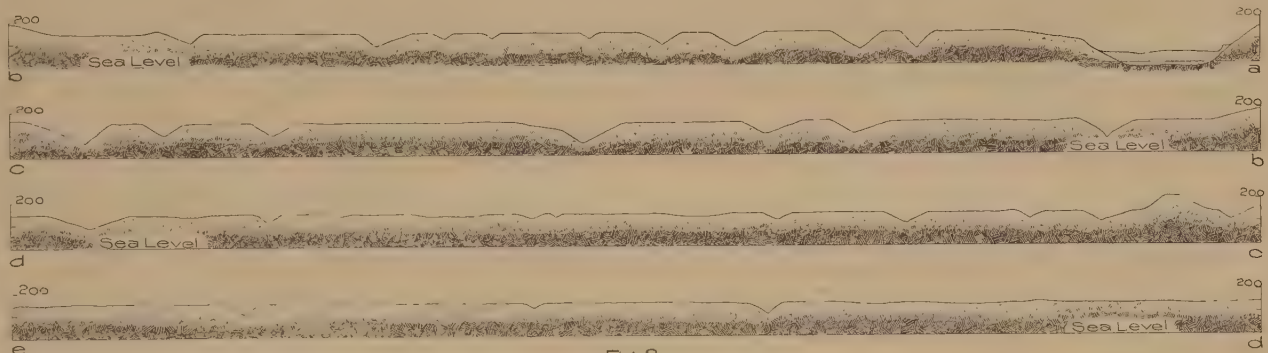


Fig 2
Section of the San Carlos Embankment Line showing the dissected peneplain
Scales
Vertical 1"=800' Horizontal 1"=1600'

SECTIONS SHOWING TOPOGRAPHIC FORMS IN THE SAN JUAN VALLEY.

of the old valley and against the marginal hills. In most cases these meanders are not accidental, but are determined by the entrance of a tributary on the opposite side. It is therefore impossible to determine the position of the stream which formerly occupied this valley, from the present position of the San Juan. Sufficient boring has been done in this portion of the river channel, however, to determine the fact that the rock or residual clay slopes of the hills which at present rise above the alluvial plain continue practically unchanged beneath the alluvium. The importance of this fact in the location of the canal line is at once apparent. The line in general follows the channel of the river, but if this were strictly followed considerable rock excavation would be necessary wherever the channel swings against one of the marginal hills. It is evident, however, that by shifting the line away from the hill the rock slope will pass below the bottom of the canal so that the excavation necessary to secure the required depth will be entirely in alluvium.

The Residual Hills.—The third group of topographic forms which characterizes the Nicaraguan depression embraces the elevations rising distinctly above the present tops of the lower hills and representing portions of the surface never reduced to the level of the old peneplain. The summits of these residual hills are entirely different from the dissected remnants of the peneplain above described. The crests are always sharp and serrate with no uniformity whatever in their altitudes. As already stated these residual hills increase in frequency and magnitude toward the north, occupying the divides between the northern tributaries of the San Juan.

The hills of the Eastern Divide lying between the basins of the Deseado and the San Francisco form a characteristic group belonging to this class. Their slopes are steep and their sides are furrowed by sharp V-shaped ravines. Around their base are remnants of the old plain above which they formerly rose, now appearing as rounded hills with uniform summits. Long spurs radiate from the central mass of the Eastern Divide hills and reach the San Juan river at several points, forming the high ridges at Sarapiqui, Tamborcito, Tambor Grande and San Francisco. Another prominent group of hills belonging to this series occurs at the junction of the San Juan and San Carlos. These have a form similar to that of the Eastern Divide hills, but the group is somewhat smaller. The upper slopes are extremely steep and the sides are deeply gullied while the summit as seen from either side presents a sharply serrate outline. The altitude of the San Carlos hills is about 1200 feet. These isolated groups of high hills occur with increasing frequency toward the line formerly occupied by the Continental Divide, which probably crossed the present valley of the San Juan in the vicinity of Castillo. West of this line they decrease in frequency and height to the lake. Along the northeastern margin of the lake the hills of this class are represented by the high spurs occupying the divides between the broad river valleys. On the west side of the lake they are perhaps represented by the ranges of hills which rise abruptly from the Rivas plain and extend from its western margin nearly or quite to the Pacific. Northward from the San Juan valley these residual hills increase gradually in height and numbers, forming the divides between the lake and Caribbean drainage and the subordinate divides between the streams of each system. By their gradual increase in this direction they form the indefinite northern limit of the great Nicaraguan depres-

sion. In northern Nicaragua they attain considerable size, forming mountains which reach altitudes of five to seven thousand feet.

The Western Divide.—As already indicated, the great Nicaraguan depression was formed before Lake Nicaragua came into existence. It originally extended entirely across the isthmus, terminating to the westward at the bay which then indented the Pacific coast, a cape projecting to the northwestward between this bay and the ocean. The cape now forms the southern part of the narrow isthmus lying to the southwestward of Lake Nicaragua and separating it from the Pacific. This strip of land is not properly, therefore, a part of the Nicaraguan depression and its topography should be independently considered.

Bordering the southwestern shore of the lake and extending northwestward nearly to Zapatera island, is a very perfectly base-leveled surface, termed, for convenience, the Rivas plain. It varies in width from five to twelve miles and is continuous along the lake margin except near the Sapoa river where it is interrupted for a short distance by high hills coming down to the lake. Very little is known concerning the southeastern extension of this plain, but it is probably nearly or quite continuous around the end of the lake with the peneplain of the Nicaraguan depression already described. Its northeastern margin is the lake shore, where the waves have cut a shallow terrace backed by a cliff from ten to forty feet in height. A few low rounded hills rise above its even surface but they seldom attain heights of more than one hundred feet. In the vicinity of Rivas, where it is most thoroughly known, the plain ascends toward the southwest at the rate of about eight feet to the mile to the base of the hills which occupy the greater part of this strip and form the Continental Divide. These hills rise abruptly from the Rivas plain to heights of 800 to 1200 feet above tide, and extend northward to a point opposite the island of Zapatera where they meet the Jinotepe plateau and the serrate residual outline of the former gives place to the even constructional slope of the latter. A single break occurs in this continuous line of hills. This is the gap between the waters of the Rio Lajas and of the Rio Grande. Here the level plain bordering the lake extends entirely through the range of hills, forming a low broad gap whose summit is but fifty feet above the lake.

The manner in which this single low gap was formed is described at some length in a later part of this report (page 142), where the recent geological history of the region is given. It may be stated here, however, that the gap is the product of the familiar process of stream capture. Owing to the decided advantages possessed by the streams flowing directly to the Pacific over those flowing eastward at first to the bay of Nicaragua and afterwards to the lake, the former were able to cut back through the divide into the drainage area of the latter and divert their headwaters. In this way an eastward flowing stream originally occupying the position of the Tola, the upper Rio Grande, the Guiscoyol and the Lajas was beheaded, and the drainage of a large part of its basin was diverted to the Pacific. The deserted valley of this stream forms the low gap through which the canal route is located. It is so broad and level that accurate instrumental work is required to determine the actual summit of the Continental Divide.

The Pacific coast in the southern part of this region is formed by alternating short strips of sandy beach and bold rocky promontories. The stretches of beach are formed by the silting up of deeply cut valleys and the promontories by

the truncated points of ridges which extend down to the coast between the valleys. To the northward of Brito, the proposed western terminus of the canal, at the mouth of the Rio Grande, the hills are farther inland and fewer spurs reach the coast. A coastal plain of some extent is here developed, increasing in width to the northward until it passes beneath the recent volcanic deposits which form the Jinotepe plateau.

This coastal plain probably at one time passed around the northern end of the divide hills and was continuous with the Rivas plain to the east. With the formation of the Jinotepe plateau the tuffs of which it is composed buried this northern portion of the plain and piled up against the end of the divide hills three or four hundred feet in thickness.

Regions Adjacent to the Nicaraguan Depression.—The Nicaraguan depression and the Western Divide as above defined and described embrace the narrow belt of country to which all feasible variants of the Nicaragua Canal route are confined. The topography of the adjacent regions, however, is of more or less interest and, particularly from hydrographic considerations, has a direct bearing upon canal problems. Its main features will therefore be very briefly described.

The Lake-Caribbean Divide.—Consider first the region lying north of the San Juan, between the lake and the Caribbean. As already stated the residual hills which rise above the peneplain of the Nicaraguan depression increase in height and numbers toward the north, finally merging with the mountains of northern Nicaragua, where they reach elevations from six to seven thousand feet above tide. Comparatively little is known of any portion of this region except its western margin. The eastern part is covered with a dense tropical forest, is almost entirely without settlement, and has been only partially explored.

The divide between the lake and the Caribbean drainage passes some distance to the westward of the axis of the isthmus, being approximately parallel with the Pacific coast northwestward to the Matagalpa river, where it makes an abrupt bend to the eastward, passing around the basin of that stream. This region between the lake and the Caribbean may be described as a deeply dissected upland. During Tertiary time it was doubtless the locus of intense volcanic activity, but subsequent erosion has entirely destroyed all trace of the original constructional topography, and the location of the vents by which the volcanic rocks were erupted cannot be determined from the present form of the surface, though it might be determined by a systematic study of the distribution and variations in character of the volcanic rocks. Toward the northern end of the lake, opposite Granada, the summits of the hills present an even skyline as though they were remnants of a plateau, but this surface may be a degradational rather than a constructional plain.

The streams flowing into the lake have baseleveled their valleys for a considerable distance back into the upland, but are separated by sharp ridges and hills which occupy the divides. Although the higher portions of the divides attain somewhat uniform altitudes which increase northward, the uniformity is not sufficient to determine the former existence of a distinct plain, and it is probable that the present valleys are carved in a surface which, since its final emergence above sea level, has always had rather high relief. So far as known the trend of the ridges and lines of hills which occupy this region have been determined entirely by the direc-

tion of the drainage and is consequently nearly east and west. It is possible, however, that the original geological structure may have determined the position and direction of the streams, although they occupy the position which they would have assumed if developed normally upon a gently arched plateau.

The much greater rainfall in the eastern portion of this region has given the Caribbean streams a decided advantage, and they have pushed the divide westward probably some distance from its original position. A few cases occur which clearly indicate stream diversion. The most striking of these is the upper portion of the Rio Grande which flows to the Caribbean north of Bluefields. (See Plate II.) This river heads in the high valley of Matagalpa, from which it flows southwestward for thirty-five miles, approaching the Viejo within about five miles, being separated from that stream by a level swampy plain. The Viejo flows southwestward to the upper end of Lake Managua and it is entirely probable that the upper portion of the Rio Grande was formerly a tributary of the Viejo. From the point where it approaches most nearly to the Viejo it flows southward for a distance of twenty-five miles, and this southerly direction is continued in a tributary which enters at that point. This portion of the stream appears to have been at one time a part of the Malacapoya which enters the head of Lake Nicaragua. From the point of nearest approach to the Malacapoya the Rio Grande turns abruptly back to the northeast and for a distance of thirty miles is approximately parallel to its upper course in the valley of Matagalpa. It appears highly probable that the Rio Grande by reason of the greater rainfall in the eastern part of this region pushed the divide westward until its headwaters intercepted the upper portion of the Malacapoya. The same process was continued and the extended headwaters affected another conquest, diverting a large tributary of the Viejo. The latter capture has been so recent that the channel of the diverted stream has not been perceptibly lowered and a part of its waters in the wet season may still follow their former course to the Viejo across the intervening swampy plain. A few other cases of stream diversion are indicated by the character of the present stream channels, but none of them are so striking or important as that of the Rio Grande.

Volcanic Mountain Ranges.—As indicated above, the southern margin of the Nicaraguan depression is formed by the foothills of the Costa Rican volcanic range. This range terminates to the northwestward in the probably extinct volcano Orosi. It contains a large number of volcanic peaks, most of which are extinct while a few are quiescent or moderately active. These peaks have a striking linear arrangement and form two nearly parallel lines of vents. The line terminating in Orosi extends southeastward into Costa Rica, passing to the southward of a parallel range whose northern peak is the volcano Turrialba. These two lines are about ten miles apart, but their peaks are so high that their slopes merge and they form a single range. If the line connecting the northeastern series of peaks were continued to the northwestward through the southern portion of Lake Nicaragua it would coincide very nearly with the line connecting the peaks of the Nicaraguan range. The latter range terminates to the southward in the extinct volcano of Madera; thence it stretches to the northwestward, terminating in the volcano Coseguina which occupies a peninsula projecting into the gulf of Fonseca. Between these two extreme peaks there is a large number

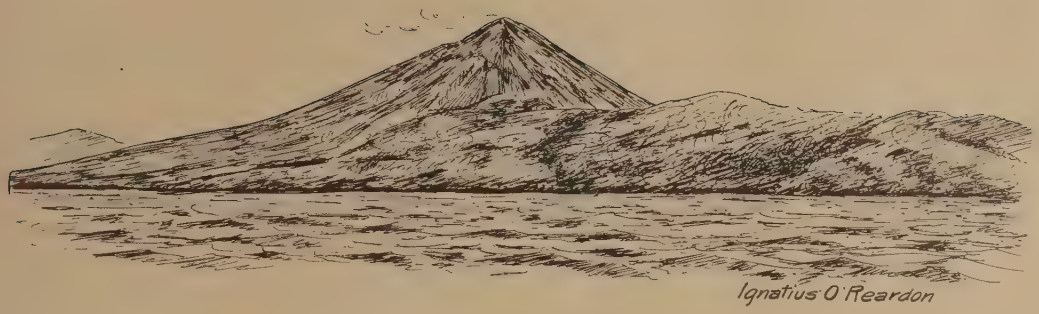
of extinct, quiescent or active volcanic vents forming more or less isolated mountains. Of these Ometepe, Masaya, Momotombo and several others to the northwest of the latter have been in eruption within historic times. Others are in the solfataric stage, while still others appear to be entirely extinct. The group of peaks between Momotombo and Coseguina is called the Marabios range.

It is probable that the vents which formed the Costa Rican range broke out upon a somewhat elevated plateau, while those which formed the Nicaraguan range were at first submarine. The latter, also, are farther apart, except those northwestward of Momotombo, which form the Marabios range. This may explain the greater height and massiveness of the Costa Rican range, and the amount of material erupted from the two series of vents may not differ greatly.

As already indicated it is probable that the form of the Pacific coast has been materially modified by this recent volcanic activity. The whole of the country between the northern portion of Lakes Nicaragua and Managua and the Pacific consists entirely of recently ejected volcanic material, and the region which it now occupies was doubtless a portion of the Pacific until recent geologic times. The former coast line is represented on the sketch map forming Plate II. The surface of this newly-added land is composed of level or gently sloping plains, isolated conical volcanic peaks and the more crowded peaks of the Marabios range. Types of the entirely isolated peaks are Ometepe and Momotombo. Both of these are composed of alternate layers of lava and ash. The latter, however, gives them their perfect conical form. Both have been in eruption within historic times and considerable smoke still comes from Momotombo. (Plate IV.) Only a small amount of steam and sulphurous vapors are at present emitted from the crater of Ometepe. Modification by the ordinary processes of erosion, in the form of these steep cones of unconsolidated ash, is extremely rapid and their summits vary in detail of outline from year to year. Madera and Zapatera are volcanoes which have been extinct for some time and the agents of degradation have materially reduced their height and destroyed the original conical form of their summits. The unconsolidated ash has been largely removed from their upper portions, leaving only the massive lava beds in place. Hence their formation has been ascribed to a different form of eruption from that which produced Ometepe and Momotombo. It is probable, however, that the summits of the former once consisted of ash cones and that the eruptions in all have been accompanied by more or less explosive violence to which the unconsolidated fragmental material is due. The lower slopes of Mombacho are rather smooth and symmetrical, but instead of a single cone its summit is truncated and forms a series of ragged peaks which surround a deep depression occupied by a small lake. There is a tradition that this mountain formerly had a conical summit which was destroyed by an explosive eruption. The present appearance of the mountain makes it extremely probable that this tradition is based upon fact. Its outline closely resembles that of Coseguina, and, as is well known, the latter was formerly capped by a symmetrical cone which was blown off in the explosive eruption of 1835. This was perhaps the most violent recorded eruption of this character up to the time of the eruption of Krakatoa in 1883. Since this final burst of activity Coseguina has remained perfectly quiet. The volcano of Masaya, which erupted a flow of lava in 1858, is at present a mountain of moderate height, about

2200 feet. It occupies the position, however, of a mountain which may once have been very much higher. The former volcanic peak occupying this position was destroyed, not by an explosive eruption, but by engulfment. The peak now occupies a depressed area having an oval shape and regular outline about four by six miles. It is located a little north of the center of this depression, the northern portion of which its lavas have nearly filled, flowing out over the edge at several points upon the surrounding country. The outlines of the depression, however, can be traced continuously with the exception of these few breaks where its rim has been overtopped by the recent lava. It is nearly everywhere a vertical cliff, descending abruptly from the level or rolling plain. The southern end of the depression which is not filled by the lavas of Masaya is occupied by the waters of Lake Masaya. The lake has a crescentic form and is bordered on the convex side by the vertical cliffs of the caldera wall rising 360 or more feet above its surface. On the concave side it is bordered by the gentle slope of the lavas of Masaya. It appears, therefore, that a portion of the volcanic plateau and perhaps a volcanic cone of considerable height have disappeared by engulfment, and that a subsequent eruption at the same point has partially filled the depression, building up a new cone over the same vent, though not to so great a height as the former one. This new cone is Masaya. It has the rather low dome shape characteristic of cones composed largely of lava flows and is broadly truncated by a double crater. A similar engulfment has occurred south of Masaya, forming the present Lake Apoya. The latter depression did not coincide with a volcano but occurred on the northern side of Mount Catrina, a low ash cone, carrying down one side of the latter and a portion of the adjacent plain. The depression is somewhat smaller than the one occupied by the lake and volcano Masaya, being nearly circular and about four miles in diameter. The depression is now occupied by the waters of Lake Apoya, the surface of which is 260 feet below the lowest point of the surrounding rim and about 1500 feet below the highest point of the rim. This highest point probably coincides very nearly with the former volcanic peak, although the latter being composed almost entirely of unconsolidated ash has been very much reduced in height by erosion. Several other caldera lakes of this type occur in the vicinity of Managua.

Volcanic Plateaus.—Reference has been made to a plateau lying southwest of Lake Managua and the northern end of Lake Nicaragua, which I have called the *Jinotepe plateau*, from the principal town upon it. This plateau is composed entirely of recently ejected volcanic material, chiefly a partially consolidated volcanic tuff which was spread out in the form of a semi-liquid mud. The plateau has an altitude along its northeastern margin of twelve to eighteen hundred feet. From this gently undulating summit it descends gradually southward and southwestward to its margin against the older rocks to the south and to the Pacific coast. The central portion of the plateau has been but little modified by erosion and probably preserves very nearly its original constructional form. This is due largely to the porous nature of the volcanic ash of which the surface is composed. The rain waters sink into the ground before they have an opportunity to collect into sufficient volume to effect any modification of the surface except where the original slopes were very steep. A belt along the coast, however, has been rather deeply dissected by stream channels, where the



VOLCANO MOMOTOMBO FROM LAKE MANAGUA.

smaller intermittent tributaries are collected into permanent trunk streams and where the plateau has a decided seaward slope. Toward the north and northeast the plateau is terminated by a somewhat abrupt escarpment which separates it from the lower plain of Leon and from the plain lying between Lakes Managua and Nicaragua, These lower plains have precisely the same origin as the Jinotepe plateau, and it is quite possible that at one time the lower and higher plains may have been continuous, but were subsequently separated by a depression of the region to the northeast. In other words, the escarpment which limits the Jinotepe plateau to the north and east may possibly mark the line of a rather recent fault. The escarpment has been deeply scored by stream channels so that it does not now have the characteristic form of a recent fault scarp but the character of the materials of which it is composed are such that it would be rapidly modified, and so retain its original form but a short time.

CLIMATE.

The climatic conditions prevailing in this region have so direct a bearing upon its geology and physiography that a brief statement of the more important characteristics of the climate is essential. Lying only ten degrees north of the equator the climate of the region is tropical, frost being entirely unknown. Furthermore since it forms a narrow belt between two oceans its climate is also insular, the annual range of temperature being very much smaller than all continental areas experience.

Amount and Distribution of Rainfall.—Throughout the greater part of the year the trade winds prevail with fairly constant direction and force. These winds are probably deflected slightly to the northward by the high voncanic range of Costa Rica, and to the southward by the mountains of central and northern Nicaragua. The low gap across the isthmus constituting the Nicaraguan depression, thus receives considerably more wind than would be due to the normal trades. It is probably this congestion of the air currents that causes the exceptional precipitation in this region. Coming from the warm Caribbean sea the trade winds are saturated with moisture, and as they strike the slightly elevated land forming the isthmus the precipitation is there very abundant. Within the zone of maximum precipitation which embraces the coastal plain and the adjacent hills, forming a belt from 50 to 100 miles wide, the annual rainfall reaches nearly 300 inches. Beyond this belt at increasing distances from the Caribbean coast it decreases very rapidly, and in the western part of the region the annual rainfall is less than a third of that on the eastern coast.

More important, however, than the absolute amount of rainfall is its distribution throughout the year. The isthmus may be divided into two distinct and well marked subdivisions by a line coinciding approximately with the present divide between lake and Caribbean drainage and crossing the San Juan near the point where that river leaves the lake. In the eastern division the rain is distributed with tolerable uniformity throughout the entire year. There are some years in which little rain falls for a period of three or four weeks in August and September, but this scarcely constitutes a dry season. In the western division, on the other hand, there is a distinct dry season of five or six months, in which there is practically no rainfall. The rain begins about the middle of May when the trade winds become less constant and an occasional storm comes from the northwest.

Physiographic Effects.—These climatic differences between the eastern and western portions of the region give rise directly to very striking differences in vegetation, and either directly or indirectly to differences in the appearance and structure of the soils, in the topographic forms of the land surface and in the effectiveness of various physiographic processes.

Eastern Division.—The eastern division, in which the rain is distributed with tolerable uniformity throughout the year, is covered with a dense tropical forest. The only breaks in this forest are the stream channels and the open lagoons, or those so recently silted up that the soil is not sufficiently firm to support large trees. Throughout this region there are no human habitations except in the few small towns along the coast and an occasional hut in a clearing upon the banks of the rivers. There are no roads or other means of intercourse except by way of the streams.

The most directly apparent effect of the forest is to protect the land surface from erosion. The falling rain is intercepted by the canopy of foliage, and filters down gradually to the surface, where the smaller vegetation consists largely of palms whose broad leaves afford a still further protection so that the soil never receives the direct impact of the raindrops. Since there are no forest fires the surface is more or less perfectly covered with forest litter which acts as a further protective covering to the soil. The character of the soil will be described more fully in treating of the regolith, but it may be stated here that the surface of this eastern division, wherever it rises above the level flood-plains of the streams, is composed of a tenacious red clay. This clay never becomes dry enough to be intersected by shrinkage cracks and is of course never loosened by the action of frost. Although it is penetrated by roots and to some extent by the burrows of insects, it nevertheless resists degradation to a remarkable degree. It was often observed that during a heavy rainfall the water flowing from the steep hillsides would be scarcely at all discolored by sediment. After a careful study of the region it was concluded that the absence of frost more than counterbalances the enormous rainfall and that degradation of the surface is, on the whole, slower than in temperate regions where the rainfall is less than a quarter of that in Nicaragua but where the surface soil is thoroughly loosened by the action of frost. Many of the small brooks which carry water throughout the year and have very steep gradient, flow in shallow channels cut in this clay. The clay often forms cascades and appears to offer more resistance to corrasion than many varieties of rock. Although the hill slopes are steep they are comparatively smooth, not deeply gullied, as is usually the case in temperate regions, and it is only after the water has collected in considerable volume that it is able to lower its channel through the clay to the underlying rock. A further effect of the vegetation, and hence indirectly of the climate, is that many of the streams are filled with an abundant growth of vegetation by which their current is checked and their effectiveness as an eroding agent correspondingly reduced. The decay of vegetable matter is so rapid that there are no considerable accumulations of such matter either in the forest generally or in the lagoons and swamps. In boring through the alluvial flood-plains, many of which have once been open lagoons, while an occasional log was encountered, nothing was found in the nature of peat, and the silt contains only a relatively small proportion of finely comminuted organic matter. On well-drained surfaces, such as moderately steep hill-

sides, there is generally no humus layer. The red soil, practically free from incorporated organic matter, forms the surface, only in part covered by the forest litter.

Western Division.—In the western division, particularly that portion of it lying west of the lake, the distribution of the rainfall produces a distinctly different type of vegetation. This region is characterized by open savannas in which the trees are small and grow in isolated patches, the greater part of the surface being open and covered with grass or small bushes. These savannas are probably due to deforesting, in part by clearing for cultivation and grazing, and in part by fires. Wherever a forest covers the surface its character is entirely different from that in the eastern division. It has the thorny habit and scant foliage which characterizes the vegetation of a semi-arid region. The light is not cut off by the foliage of the higher trees, and hence the smaller herbaceous vegetation is much more abundant than in the eastern division. Fires prevail in the dry season so that the forest litter does not accumulate, and at the beginning of the wet season, before the vegetation is renewed, the surface is entirely unprotected from the effects of the heavy rainfall which inaugurates that season.

Red soil is rarely seen west of the lake, the prevailing colors being blue, bluish-gray or black, and this is quite independent of the character of the rock from which it is derived, since the rocks are essentially the same as those which yield red soils in the eastern division. Toward the end of the dry season the surface is intersected by many deep cracks, often two or three inches wide and as many feet deep, which effectually destroy the coherence of the clay. This alternate saturation and baking of the soil, therefore, effects somewhat the same result as that accomplished elsewhere by frost. It also permits the incorporation of much organic matter with the upper portions of the soil, forming an exceptionally thick humus layer. From these and perhaps other conditions it results that the smaller rainfall of the western division is a very much more efficient agent of erosion than the greater rainfall of the eastern division.

The effect of these climatic conditions is seen in the topography which characterizes the region west of the lake. The hills are extremely steep and deeply gullied. At the mouth of each ravine there is an alluvial cone, showing that a heavy load of coarse and fine detritus is moved by the occasional flood which the ravine carries. The depth of the residual material, the *regolith*, is also very much less on the west side than it is on the east. This is doubtless due in part to the fact that the conditions of rock weathering are less favorable in the former than in the latter region, but it is also due in part to the more favorable conditions under which the agents of degradation act. Both of these factors, however, are directly dependent on climate.

Another factor which on the west side may be effective in modifying topographic forms is wind erosion. During the dry season when the protecting vegetation has been removed by forest fires, the steady force of the trade winds raises clouds of dust, and the total amount of transportation effected by this agency must be very considerable. The effects are most noticeable on the lake and ocean beaches where the sand is driven with great force and piled up in dunes. Roads on which there is sufficient travel to keep down the vegetation are usually sunk below the surface of the adjacent country. The track is often bordered by a vertical bank from five to fifteen feet high, and a part of this erosion is doubtless due to wind action.

ROCK FORMATIONS.

Conditions for Study.—The geology of the region under consideration has been examined in detail only in the vicinity of the route of the proposed canal. Even where studied most carefully the relations of the various rock formations are extremely obscure. This obscurity arises chiefly from the nature of the exposures which must be depended upon in making out these relations. East of the lake rock exposures are very infrequent, and it is practically impossible from them alone to determine the relations of the various rock formations. The vegetation is so abundant that no distant views can be obtained, and the information which can usually be derived from a broad study of the topography is entirely wanting. The extreme depths to which the rocks are decayed and the uniform mantle of red clay which covers their outcrops effectually conceal their distribution and relations. The larger streams, as already explained, are chiefly flowing in old valleys which they are now silting up. Since they are not corrading their beds, their channels furnish exposures of materials other than alluvial only where they happen to impinge upon the adjoining hills in their broad meanders. The only exception to this general statement is the San Juan between Castillo and Machuca. The conditions west of Lake Nicaragua are somewhat more favorable. The vegetation is not so abundant, and the removal of the residual matter has more nearly kept pace with the rock decay; also the slopes are more abrupt, and most of the streams are corrading their channels except in the lower portions of their valleys.

No attempt was made in the field to do areal mapping, and the distribution of the formations represented on the accompanying map (Map No. 1, Sheet 2) must therefore be regarded as in most cases only approximate. For the reasons stated above the most detailed areal work would secure but little additional information concerning distribution in some portions of the region.

Classification of the Rocks.—The rocks of the region are placed in two groups, Tertiary and post-Tertiary. Each includes both igneous and sedimentary formations. No rocks certainly older than the Tertiary occur along the line of the canal, although such have been reported from northern Nicaragua and also from central Costa Rica. The Tertiary sedimentary formations include the Brito and Machuca.

Brito Formation.—*Distribution.*—With the exception of a few areas of intrusive igneous rocks, the strip of land between Lake Nicaragua and the Pacific is occupied entirely by the Brito formation. It extends from the Sapoa river to a point opposite the island of Zapatera. Remnants of the formation are also found along the lake shore to the southeast of Sapoa, and its present outcrops may extend continuously eastward to the area occupied by the Machuca sandstone. To the southward the formation is probably covered by the recent lavas of the Costa Rican volcanoes. It also probably extends some distance to the northwest of Zapatera where it is covered by the recent tuffs which form the Jinotepe plateau.

Lithologic Character.—The formation presents considerable variety in its lithological composition, but it has not yet been sufficiently studied to permit of its subdivision, even if this may be eventually possible. Much the larger mass of the formation consists of somewhat calcareous non-fissile shale. When fresh this is bluish-gray and weathers to a yellowish or brownish color. Distributed through the shale are numerous beds of sandstone. These are also some-

what calcareous and doubtless contain a considerable proportion of volcanic ash. The sandstone beds vary in thickness from a few inches to two or three feet and occur singly or in groups. The latter are sufficiently heavy to materially affect the topography in some places. These sandstones, like the shales, are blue when entirely fresh, but are always weathered at the surface to some shade of yellow or brown. The hills immediately west of Rivas, rising abruptly above the Rivas plain, are due chiefly to the presence of these resistant sandstones. They occur most abundantly, however, near the Pacific coast and are well exposed in the headland northwest of the Rio Grande valley at Brito. The beds here have a general, though somewhat variable, dip to the southwest, hence the higher portions of the formation make the cliffs along the Pacific. This seems also to be its most variable portion. In addition to the shales which constitute its greatest bulk to the eastward, it here contains also beds of sandstone, conglomerate and coarse volcanic breccia on the one hand, and on the other marly beds and lenses of pure limestone. Forming a part of the headland south of Brito is a bed of limestone something over a hundred feet in thickness. Small outcrops of this bed, or one very similar, have been noted at several other localities to the eastward in the Divide hills. Its limited extent is due in part to erosion, since the dip of the bed would carry it above the tops of most of the hills to the eastward, but it is doubtful if its original extension was very great. Several of the limestone outcrops noted are probably small lenses in the shale and not connected with the more continuous bed at Brito. A portion of this limestone has a peculiar concretionary structure, some of the concretions attaining a diameter of an inch and a half while other portions of the bed are oölitic. Immediately west of this exposure of limestone, forming a group of islets nearly covered by high tide, is a very coarse volcanic conglomerate or breccia. The larger fragments are a foot or more in diameter and quite angular, and from this extreme they grade downward to small pebbles some of which are well rounded. The present relations indicate that the conglomerate is the stratigraphical equivalent of the limestone, replacing it within a few yards. In some places the two rocks are seen to merge, the limestone containing numerous angular fragments of volcanic rock. At other points along the coast both north and south of Brito similar conglomerates occur. Their bedding is extremely irregular, and they afford evidence of having been formed rapidly and near the source from which their constituents were derived. While it is possible that the source of this material may have been to the eastward it seems much more likely that it came from volcanic vents to the southwest, from volcanoes which have been entirely removed by the waves of the Pacific.

Although their connection has not been continuously traced it is assumed that the sedimentary rocks found at various points along the southern margin of the lake east of Sapoa, belong to the Brito formation. This region was examined by coasting along the lake shore, so that it was chiefly the rocks forming the projecting headlands which were observed. These consist almost entirely of sandstones very similar in appearance to the sandstones found interbedded with the Brito shales, and also conglomerates and breccias similar to those occurring at various points along the Pacific coast.

Structure.—(See general geological sections, Plate XVI.) The Brito formation wherever observed was found to be intersected by numerous

joint planes as shown in Plate V. In some places these occur as two well-developed sets of approximately parallel planes which intersect each other at right angles. In others the joint planes are very numerous and irregular, cutting the beds in all directions. The latter form is less common and appears to be confined to rather narrow zones where shearing and faulting have probably taken place. The frequency of the joint planes varies with the thickness of the beds. The rhomboidal blocks into which the beds of shale and sandstone are broken usually have diameters approximately equal; that is, the more massive the original beds the farther apart are the intersecting joint planes. These joints have permitted the percolation of surface waters to great depths and have facilitated the deep weathering which is generally observed. The weathering proceeding outward from the joints has resulted in the formation of concentric layers about a core, which coincides with the center of the original rhomboidal block. The accompanying illustration, Plate V, is from a photograph of the Brito sandstone exposed in a ravine near La Flor. It shows the effect of the jointing and to some extent the subsequent concentric weathering in the sandstone. The resulting rounded blocks in some places give the appearance of a rude rubble wall. In the vicinity of Las Lajas the horizontal sandstone beds have been laid bare by the action of the waves, and where the rhomboidal blocks produced by jointing have been rounded by concentric weathering, the appearance is that of a cobble pavement.

The Brito formation has suffered only a moderate amount of disturbance since its beds were deposited. Where its rocks are best exposed along the Pacific coast numerous small faults are observed, the displacement in many cases being but a few inches. The inclination of the beds is generally under 20° though in a few localities the disturbance has been much greater and the dips increase up to the vertical. Neglecting these minor irregularities the dominant structure is a broad anticline whose axis extends in a northwest-southeast direction approximately parallel with the Pacific and lake shores and a short distance southwest of the latter where the beds are approximately horizontal. The greater portion of the region between the lake and the Pacific, therefore, is occupied by the western limb of the anticline and has prevailing southwest dips. From San Jorge to Lajas the dips are somewhat variable but generally to the northeast. The greater part of the eastern limb of the anticline is covered by the lake. The numerous exposures of the Brito formation along the southern margin of the lake from the Sapoa to the Rio Orosi belong to this eastern limb of the anticline, and the beds have northeasterly dips of 5° to 30°. The strike of these beds is not strictly parallel with that of the beds on the Pacific coast. They converge slightly toward the northwest, indicating a pitch of the anticline in that direction.

The exposures of the Brito formation are so infrequent and the dips are so variable that no satisfactory measure of the thickness of the formation can be obtained. Taking the observed dips between the Pacific coast and the lake shore the thickness exposed is estimated at about 10,000 feet. This of course is not the total thickness of the formation, since the bottom is not exposed at the axis of the anticline. Also the formation has undoubtedly suffered an unknown but considerable diminution in thickness by erosion, and there are no data for determining the thickness of strata which have been removed from the highest beds now observed.

THE BRITO FORMATION NEAR LA FLOR.

Interbedded sandstone and shale showing intersecting joints and concentric weathering.

Utilization.—Most of the sandstones of the Brito formation are too thin-bedded for utilization as building stone. This is the character of the beds exposed in the northern Brito headland, although a part of them at least might be utilized for concrete and rip-rap work. About half a mile back from the coast a group of heavy sandstone beds occurs in the shales. They form a spur from the hills to the north extending out a short distance into the Rio Grande valley. These beds would probably yield a good quality of building stone. They would be easily quarried in dimensional blocks up to twenty or more inches in thickness; would dress readily and be as durable as the average sandstone.

Age of the Formation.—The greater part of the Brito formation is apparently barren of organic remains. The only locations at which fossils have been found are on or near the Pacific coast. This, however, may be due to the fact that the rock exposures are not elsewhere of such a character as to facilitate the discovery of fossils, and the latter may possibly be more generally distributed than present knowledge would indicate. The fossils are confined almost wholly to the limestones and marly beds. They consist of corals, moluscan and foraminiferal remains. The latter are especially abundant. The rather meager collections have been submitted to Dr. Dall for determination. He pronounces them Oligocene and probably identical with the foraminiferal beds described by Hill from the Caribbean coast at Panama. One of the most abundant forms is a small numulite, *orbitoides*, probably *forbesei* which is characteristic of the lower Oligocene. The moluscan remains were collected on the Pacific coast about seventy-five miles northwest of Brito in what was supposed to be a higher portion of the same formation. Dr. Dall states that these have the upper Oligocene aspect though there are not enough of them to be conclusive. He thus confirms the view entertained in the field that successively higher beds in the Brito formation are exposed along the coast toward the northwest.

In addition to the fossils on which is based the above conclusion concerning the age of the Brito formation it also contains rather abundant plant remains. They are in the form of driftwood and coal, and as yet no remains sufficiently well preserved for identification have been discovered. Associated with the coarser sandstones are numerous blocks of wood whose rounded forms suggest that they are fragments of drift which were incorporated with the sand and gravel while it was accumulating. In some cases they still contain a large proportion of their original carbon, and in others this has been more or less perfectly replaced by silica or iron pyrites. The coal occurs associated with the finer sediments, and although a careful search was made, the thickest seam observed was under half an inch. While sufficient carbonaceous matter is sometimes disseminated through the shales to give them a black color, no indications were found pointing to the existence of workable coal deposits in the region examined.

Coal in workable quantity has been reported from the region southwest of the lake, between the lake shore and the Costa Rican volcanoes. The exact locality is on the Rio Hacienda, twelve miles from its mouth. It was not visited and no samples of the coal were seen, so that the report lacks verification. There appears to be no reason, however, why conditions favorable for coal accumulation should not have prevailed in some portions of this region during the deposition of the Brito beds.

Machuca Formation.—*Distribution.*—The immediate margins of the San Juan valley from

the lake eastward to Castillo are, so far as known, composed entirely of igneous rocks. From a point a few miles below Castillo to another midway between Machuca and the Boca San Carlos, the rocks are largely sedimentary, although they contain some igneous rocks in the form of small dikes. These sedimentary rocks constitute the Machuca formation. Its present extent is known only in the immediate vicinity of the river. The region south of the upper San Juan, forming the lower valleys of the Frio and Poco Sol, is geologically unexplored. It is therefore possible that the Machuca formation may extend westward through this region and be nearly, if not quite, continuous with the outcrops of the Brito formation south of the lake. Until this connection is established, however, the original continuity of the two formations is a matter of doubt.

Lithologic Character.—The rock exposures in this region to the eastward of Castillo are very much less satisfactory than those along the Pacific coast; hence the character of the Machuca formation is not so well known as is that of the Brito. Like the latter, it appears to consist chiefly of calcareous shales with which sandstones are interbedded. The constituents of the rocks are largely igneous in their origin, but there are no coarse conglomerates or breccias such as occur in the Brito. Also no pure limestones or distinctly marly beds have been discovered, although the examination of the formation has not been sufficiently exhaustive to enable one to say that such beds do not occur.

Structure.—(See general geological sections, Plate XVI.) The exposures are comparatively few in which the dip of the Machuca sandstones can be determined. At the Cano Bartola the dip is about 15° and to the north. At Machuca it is 20° and to the northwest. These dips suggest the presence of a synclinal basin, the southern end of which is crossed by the San Juan. They are not sufficient, however, to locate its axis. Although in general the dips are light, the formation has suffered considerable local disturbance. Breccias, probably due to faulting, have been observed at several points, the best example being the ledge which projects into the river opposite the mouth of the Machuca. Also numerous sharp folds occur in the vicinity of Machuca. The same evidence of faulting and folding would probably be found elsewhere if the exposures were sufficiently abundant to render the structure determinable.

The rocks of the Machuca formation are generally found deeply weathered. The weathering is hastened by the igneous constituents which they contain, and the final product is a residual red clay which is indistinguishable from the product of the decay of igneous rocks. Except for the fresh rock obtained beneath the residual mantle by means of the diamond drill, it would have been impossible to determine even approximately the limits of the sedimentary and igneous rocks. At some points, as at Machuca, the sandstone contains a very large proportion of iron pyrites which by oxidation also tend to hasten its decay.

Nearly everywhere the beds are intersected by numerous joint planes, the only marked exception being the rather massive interbedded sandstones exposed on Machuca creek. Weathering has proceeded inward from the joints toward the centers of the rhomboidal blocks producing concentric shells about a central nucleus exactly as in the Brito formation.

Utilization.—The beds of massive sandstone exposed on Machuca creek, being to a large extent free from joints, could probably be quarried for dimensional building stone. This stone

would be easily worked and fairly durable. The chief difficulty in quarrying would be the extent of the stripping required which would doubtless be considerable. These are the only beds known in the region east of the lake from which dimensional stone could be obtained.

Age of the Formation.—No fossils have as yet been found in the Machuca formation which are sufficiently well preserved for specific determination. At Cruzita, one mile below Machuca, the core from the diamond drill hole in the bed of the river contains numerous indistinct organic forms. The rock is described by Dr. Ransome as an andesitic tuff containing fragments of limestone. The organic forms are revealed by the weathering of the rock with the removal of the soluble limestone, and they are also shown in the thin section under the microscope. While they cannot be identified, they strongly suggest the forms which occur so abundantly in portions of the Brito formation. The beds in which they occur are evidently derived in large part from fresh volcanic tuff, though the latter was not so abundant as to prevent the growth of organisms in the sea in which it was being deposited. In the absence of conclusive fossil evidence, therefore, the age of the Machuca formation, so far as it may be determined, rests upon other and less satisfactory evidence. It is believed to be nearly or quite contemporaneous with the Brito formation, that is, Oligocene (Tertiary). The grounds on which this conclusion is based are briefly as follows: (1) There is a general similarity in lithologic composition and appearance between the two formations. (2) Both have suffered about the same amount of deformation, elevation and erosion since they were deposited. The value of this fact for correlation depends upon the proximity of the areas which they occupy and the evidence that the recent geologic conditions have been similar in both. (3) Both formations bear about the same relation to a group of igneous rocks which was in part contemporary with them and in part subsequently invaded their beds. The differences in composition of these intrusive rocks are not greater than differences in igneous rocks within the same area which are known to be nearly or quite contemporaneous. (4) Finally, as pointed out above, it is possible and even probable that the two formations are nearly or quite continuous through the southern part of the upper San Juan valley.

In the vicinity of the Toro rapids, some distance westward from the present limit of the Machuca formation, a few siliceous boulders have been found which contain fossil remains. The original location of the beds from which these boulders are derived is not known, though they have probably not been transported a great distance. These fossils are unfortunately only casts. They have been examined by Dr. Dall who says they "are not determinable, but have the general look of a fresh-water assembly." They are not regarded, however, as having any special bearing upon the age of the Machuca since it is by no means certain that they have been derived from that formation.

Tertiary Igneous Rocks.[1]—As stated above, the beds of the Machuca formation occupy a broad belt which crosses the valley of the San Juan extending from a point a little below Castillo eastward some distance beyond Machuca. While this formation contains a considerable proportion of volcanic material and is intersected by numerous dikes, it contains no lava flows and

[1]The writer is indebted to Dr. F. L. Ransome, of the U. S. Geological Survey, for a petrographic examination of the igneous rocks collected in Nicaragua, and for the determination of the rock species. Dr. Ransome's petrographic notes are appended to this report as Part III.

no beds, the constituents of which are exclusively of volcanic origin. In the remainder of the country between the lake and the Caribbean, wherever the underlying rocks or their residual products rise above the recent alluvium of the flood-plains, the rocks are almost entirely of volcanic origin. They present a great variety in structure and appearance, varying through the extreme types of volcanic products from distinctly stratified beds of fine volcanic ash, through well-rounded conglomerates, fine and coarse angular breccias, surface lava flows and intrusive masses of rather coarsely holocrystalline rock which did not reach the surface before cooling.

Massive Igneous Rocks.—The principal varieties of igneous rocks which are found between the lake and the Caribbean are *augite andesite*, *olivine basalt*, *hypersthene basalt* and *dacite*. Of these four varieties the first three are very similar in appearance. They belong to the class commonly designated as trap rocks. They are dark bluish-gray to black in color; generally fine-grained but often containing certain minerals as olivine and feldspar which can be readily distinguished with the unaided eye. They are generally compact and heavy, though a well-marked vesicular structure characterizes some portions of the basalt. The red clay which is the final product of their decay contains numerous residual boulders of the fresh rock covered with a thin ocherous crust.

The dacite is light gray in color and is made up of abundant quartz and feldspar crystals embedded in a fine-grained or glassy, gray groundmass. It is lighter than the trap rocks and is considerably softer, even when entirely unweathered. The dacite contains numerous fragments of darker basic rocks. It doubtless reached its present position as a lava flow, and these inclusions are fragments of the underlying rock which were picked up and incorporated in the molten mass during its passage through the lower formations to the surface. Many of them are a soft greenish rock exactly like the tuff on which the dacite rests. The presence of these included fragments of a different rock is doubtless the reason the dacite was called conglomerate in the Canal Company's Eastern Divide sections. Of the fragmental igneous rocks two classes may be made, according as their igneous or sedimentary characteristics are the more prominent. In the first class are included the tuffs which form the western portion of the Eastern Divide, passing under the dacite at an angle of about 5°. This tuff is related to a basic lava either andesite or basalt. It has a dark greenish color and very fine grain. It is soft and talcose, and on exposure to the air the cores generally crumble into small fragments. While this tuff owes its kaolin-like character to the decomposition of a basic glass, it was probably never a hard rock. The pressure to which it has been subjected since its deposition has apparently not been sufficient to produce complete induration.

The extent to which these rocks have weathered has been already pointed out, but may be referred to again in explanation of the difficulty which has been experienced in determining the relations of the various members of the volcanic formations. All weather to a red clay, and exposures which afford any indication of the original character of the underlying rock are extremely infrequent. The chief reliance must be placed upon the occasional residual boulders, upon the presence or absence of quartz grains in the clay and upon the occassional cut banks along the streams. The large-scale sections of the proposed dam sites which are published with

this report, indicate the complexity of the relations between the various volcanic formations, and the hopelessness of attempting to work out these relations from surface indications alone, without the aid of sections derived from drilling. For the reasons given above it is practically impossible to map the surface outcrops of these various rock varieties. Their distribution can only be indicated in a general way.

The rock forming the hill on which San Carlos is located consists of augite andesite. This extends eastward down the river to the Rio Melchorita forming the hills which rise above the level alluvial plains. At Palo de Arco occurs olivine basalt, and this rock continues eastward a short distance beyond Castillo. At the Savalos it presents an amygdaloidal phase, and in the hill near the mouth of the Santa Cruz it consists of a very coarse breccia. The high hills at the junction of the San Carlos with the San Juan consist of hypersthene basalt. This is a holocrystalline rock and one which probably cooled at some distance below the surface. It may possibly mark the center of eruption from which lavas in the surrounding region, which have a similar composition but less perfect crystalline structure, were derived. A similar but less crystalline rock also occurs in the hills on the north side of the San Juan river. To the eastward at Ochoa the hypersthene basalt occurs south of the river, while the rocks at the river bank on both sides and extending to the northward are olivine basalts. This olivine basalt extends eastward beyond the San Francisco hills. At the Tambor Grande it is replaced for a short distance by dacite, then in the Tamborcito hills by hypersthene basalt, but again comes in in the Sarapiqui hills and thence extends eastward forming all of the hills which border the lower portion of the San Juan river and also those about Silico lake. The dacite, while it does not reach the surface at Ochoa, was encountered there in boring. It was also found at lower Ochoa beneath a bed of volcanic tuff or breccia and some unconsolidated sediments. It comes to the surface at Tambor Grande and is probably continuous northward in the high ridge connecting the Tambor Grande hills with the Eastern Divide. It forms the surface through the higher portion of the Eastern Divide overlying andesitic tuffs and passing under basalt.

Fragmental Igneous Rocks.—Since the closely related fragmental rocks, both the bedded tuffs and the conglomerates, do not weather in such a way as to furnish residual boulders, their presence is much more difficult to detect. From the character of the exposures in the bluffs along the San Juan river, and from the results of the drill sections, it seems probable, however, that the bulk of these fragmental rocks is as great or greater than that of the massive rocks. About four miles above the Boca San Carlos these beds are exposed in a high bluff on the north bank of the river. There is shown a considerable diversity in the character of the material, varying from the finest tuff to coarse rounded conglomerate. All parts of the beds are equally weathered, forming a tough clay quite free from grit. The different beds vary considerably in color, although the prevailing colors consist of various shades of red and brown. The planes of stratification between the different beds are not sharply marked, and the indications are that the deposit was made rather rapidly and in the presence of strong currents. Similar exposures of thoroughly decayed sedimentary beds occur in the river bluffs at various points between Ochoa and the mouth of the San Francisco.

It is probable that during the extrusion of the

volcanic rocks in this region numerous bodies of water were formed by the interruption of drainage lines by the lava flows. In these bodies of standing water the finer tuffs were accumulated with considerable regularity in their planes of stratification. Forests were present on the adjoining shores and much vegetable matter was accumulated along with these silts. There thus resulted deposits of considerable depth such as those encountered at lower Ochoa (see Fig. 6, Plate XVII). These were subsequently covered by lavas or deposits of fragmental material but have never been buried sufficiently deep to bring about their complete consolidation. In some places conditions were favorable for the deposition of calcareous material. In the section at the San Francisco a bed of very fine-grained earthy limestone about three feet in thickness was encountered with fine volcanic tuff above and below. The limestone was perhaps originally a calcareous mud which has been thoroughly solidified and is now comparatively hard. The adjacent tuffs both above and below may have been solidified at one time but are now soft and talcose. No traces of organisms can be detected in this limestone, and it may have been precipitated from solution without the intervention of life. In the railroad cut near Silico lake there occurs a bed of clay enclosing water-worn pebbles and numerous fragments of wood which is immediately overlain by a flow of basaltic lava. This clay was doubtless alluvial or accumulated in a lake and has probably not been buried to a sufficient depth to produce consolidation.

The beds of lava and volcanic tuff above described have been but little changed from the position in which they were originally deposited. Wherever bedding planes can be detected in the stratified tuffs, they are practically horizontal. The planes separating lava flows generally have a decided original inclination, and this may be increased or diminished by subsequent tilting. In the sections of the upper and lower Ochoa dam sites (Figs. 5 and 6, and Plate XVII) the planes separating the several formations have a slight dip to the northeast. The same thing is observed in the sections of the San Francisco embankment line and of the Eastern Divide (Figs. 1 to 4 and 6, and Plate XVIII). Insofar as these dips are due to deformation, they suggest the presence of a low anticline to the east of the Machuca basin, its axis approximately parallel with the Caribbean coast and crossing the San Juan near the Boca San Carlos. For reasons given above, the structure of these igneous formations as well as of the Machuca sandstone shown on the geological sections, Plate XVI, rests on a very few observations and should not be accepted with too great confidence.

Recent Alluvial Formations.—The post-Tertiary formations of the region include the recent deposits which make up the flood-plains of the rivers and the delta plains about their mouths, together with the products of the recent volcanic activity.

The character of the alluvium has been somewhat fully described in a previous section of this report and requires but little further mention. It varies in character with the local conditions under which it is deposited and with the character of the rocks from which it is derived. On the west side, filling the valley of the Rio Grande, it consists of fine brown sand and clay, derived from the decay chiefly of the sandstones of the Brito formation. In some places it contains enough calcareous cement, which has been deposited by infiltration from above, to give the alluvium a fair degree of coherence.

In the valley of the San Juan there is considerably wider diversity in the character of the

alluvium. In the upper portion of the valley it consists of fine blue clay interbedded with fine blue and brown sand. The sand occurs chiefly in the river channel and is the residuum which the sluggish current of the river has been unable to transport. It is probable that but little sand would be encountered in the alluvium at any considerable distance from the present channel. In the lower portion of the valley the alluvium in the immediate vicinity of the river contains considerable black sand, such as it is at present transporting in great volume. This occurs either disseminated through the finer silt which is derived from the decay of rocks in the adjoining region, or it occurs as distinct layers interstratified with the clay. The presence of a considerable proportion of sand in the silt renders it much firmer than when the latter consists chiefly of clay. The sand does not extend to any great distance from the present river channel, and hence the silt becomes less stable with increasing distance from the river. The material which fills the tributary valleys, such as the Danta, the San Francisco, the Cureno and the Tamborcito, is a fine silt, generally quite free from grit, with a blue color, and containing abundant fragments of wood and leaves. When this material is thoroughly drained it becomes fairly compact, as shown in the vertical banks of the most of the streams, but at some distance from these streams, where the drainage is imperfect, it is quite soft to a depth of 25 to 50 feet. This alluvial silt or mud when first exposed sometimes has a brilliant blue color which quickly changes to a yellowish brown on exposure to the air. In some cases the change in color takes place at the exposed surfaces within a few minutes after the air has access to them.

The material forming the delta plain of the San Juan is similar to that composing its flood-plains. The black sand is carried out to sea and transported along the shore by littoral currents and thrown up to some distance above tide level by the waves, so that within a belt two or three miles broad along the coast, the surface is composed chiefly of black sand with a small amount of vegetable mould. The fine silt increases in thickness from a feather-edge at its outer margin at a rate somewhat greater than the eastward slope of the delta plain. It is probable that the delta has always been fringed by a belt of sand which never rose more than a few feet above sea level. The region, however, has been sinking while the delta was forming. As the delta grew by accretions of sand to its outer margin, the corresponding growth upon its surface was made by the fine silt deposited from the flood waters of the rivers. The plane separating the sand from the overlying silt thus appears to have a gentle landward inclination, being slightly above sea level at the present coast and some distance below sea level toward its inner margin.

Recent Volcanic Rocks.—The vulcanism which gave rise to the igneous rocks associated with the Tertiary sediments appears to have become entirely extinct in this region, and doubtless a long interval elapsed in which it was free from any manifestations of volcanic activity. In comparatively recent times the vulcanism was renewed, and its products form the Costa Rican and Nicaraguan volcanic ranges which have already been described. Its products also form the Jinotepe plateau and the plain of Leon which extend northwestward from the great lakes to the Pacific. In mineralogical composition these recent volcanic products consist very largely of hypersthene andesite. The last eruption from Masaya was a basaltic lava, and a comparatively recent lava flow from Ometepe is also a basalt. With these two exceptions the

recent activity so far as observed has given rise only to andesitic lavas and tuffs. The cone of Ometepe consists largely of lapilli with occasional interlaminated lava flows. The lapilli consist in about equal parts of black or gray pumice and of black glassy rock which has been thoroughly shattered and ground up by explosive eruptions. The tuffs from this volcano which have been carried to a considerable distance from the center of eruption, chiefly by wind, are composed more largely of tufaceous material. The materials erupted from the other volcanic centers forming the various peaks of the Nicaraguan range appear to be similar in composition to those found in Ometepe. The Jinotepe plateau is composed largely, if not altogether, of volcanic tuffs which probably reached their present position in the form of a more or less fluid mud. This mud becomes solidified, but never sufficiently so to form hard rock. It is quarried in many places and used as a building stone. It can be readily cut out with a pick, but becomes somewhat harder on exposure to the air. The rock fragments which constituted this tuff vary widely in size from large boulders several feet in diameter to the finest dust. They are all angular, and in this respect they differ from the volcanic conglomerates associated with the Tertiary rocks of the San Juan valley. A further difference is the almost complete absence of stratification and sorting of the rock constituents. This tuff appears to have been sufficiently fluid to flow upon rather low slopes and the present southward and westward slopes of the Jinotepe plateau are probably the original constructional slopes. In the vicinity of Managua planes separating successive mud flows intersect the rock and are utilized in quarrying. In these quarries human tracks have been found in the rock where they were made while it was still in the form of mud. They prove the recency of the tuffs and indicate something as to its physical condition when first deposited. At the margin of this plateau the tuff is found filling the valleys in the older formations and smoothing out the former irregularities of the topography. In many cases the present streams have in part re-excavated the old valleys, though not to their original width.

The vertical cliffs surrounding the caldera lakes, Apoya and Masaya, display the underlying structure of this plateau near the centers from which its material was derived. These cliffs are composed of alternating layers of tuff and solid lava flows. It is impossible to say how far from the centers of eruptions these lava flows extend, but the distance is probably not very great. Near the centers of eruption the character of the tuff is somewhat different from that at greater distances. It is less homogeneous in character and frequently consists of sharply-defined alternating tuff beds which differ widely in appearance. In the bluffs surrounding Lake Apoya this is well shown. Numerous distinct bands of white pumice occur interbedded with dark lapilli and fragmental rocks, and these in turn are interbedded with the lava flows.

ROCK DECAY.

Importance of the Subject.—One of the features which first impresses the geologist or the engineer in Nicaragua is the extent to which the surface rocks are weathered. This feature is common to all tropical regions, at least to those in which there is an abundant rainfall. While the extent of rock weathering has an important bearing on the geology of the country, and thus a high degree of scientific interest, it is a fact of prime importance to the engineer in

planning any structures in this region. It enters directly into the cost of excavation and also into the cost and permanence of foundations for all heavy structures. The weathering of rocks is effected by two processes which should be carefully discriminated. These are *rock disintegration* and *rock decay*. By the first a rock is broken down to smaller masses or even to its constituent minerals without the alteration of the minerals themselves. The most active agents are changes of temperature and the expansion of interstitial water by freezing. Hence, in general, the activity of the process varies with latitude and in the humid tropics where the range in temperature change is slight, the effects are practically reduced to zero. By the second process the constituent minerals themselves undergo alteration and, as will be more fully pointed out below, the active agents are the acids derived from the decay of organic matter. Hence this second process varies inversely with latitude, being most active in the humid tropics and reduced to zero in the arctic regions.

It should be noted that it is the first of these processes, rock disintegration, which is chiefly inimical to the permanence of structures and hence that their relative durability is greater in the tropics than in higher latitudes.

Conditions Favoring Rock Decay.—It has been shown by various investigators that the conditions most favorable to rapid rock decay, and hence to the accumulation of an extensive mantle of residual materials, are high temperature and abundant moisture. These conditions are only indirectly responsible for a large part of the rapid rock decay which always accompanies them. They are also the conditions on which the rapid growth and decay of a luxuriant vegetation depends, and it is the latter process which is chiefly instrumental in hastening the process of rock weathering.

It is manifest that heat alone without moisture does not give rise to conditions which favor rock decay, for it is a common observation in desert regions where the temperatures reach the maximum, that rocks are disintegrated to a limited depth by the alternate expansion and contraction due to changes in temperature, but that rock decay is practically absent. On the other hand, abundant moisture and continuous low temperature do not give conditions favorable for rock decay since these conditions favor the accumulation of ice and snow. Glaciers are effective instruments for transportation of rock debris and to a limited extent are efficient as eroding agents, but practically no rock weathering goes on in their presence.

Even where the moisture is abundant and the temperature is sufficiently high for the growth of an abundant vegetation, unless the conditions are also favorable for the decay of that vegetation they are not favorable for rock weathering. This is seen in the extremely luxuriant forests of the north Pacific coast, where the successive generations of forests grow upon the remains of their predecessors. The conditions are here favorable for the preservation of vegetable remains in the form of peat, and rock decay is practically absent. It appears, therefore, that an essential condition for rapid rock decay is the rapid decay of abundant vegetable matter, and this leads to the conclusion that the most efficient factor in the process is the presence of the complex organic acids which are derived from the decay of vegetation.

Effect of Chemical Composition.—The depth to which the rock decay has gone and the character of the products depend in a considerable measure upon the chemical composition of the rock, upon its original structure and upon the subsequent alterations which it has undergone, such as fracturing in the process of

consolidation or by subsequent dynamic disturbances. But few rocks are found in this region which are not either wholly or in large part composed of material of volcanic origin. Hence their chemical composition does not present so wide a range as is usually found among sedimentary and igneous rocks. A few are apparently the products of thermal springs, and the composition of these is perhaps the best suited of any to resist the process of rock decay. Examples of rocks of this origin are found in the small hill opposite San Francisco, a short distance east of the lake and also at Chorrera on the Aguas Muertas. These are composed chiefly of silica which is the mineral least acted upon by the processes to which rock decay is chiefly due. The Machuca sandstone, as already explained, contains a large proportion of feldspathic minerals as well as iron sulphide and carbonate of lime. Hence it is peculiarly susceptible to hydration, oxidation and solution. The igneous rocks belong to the basic and intermediate classes and hence contain a large proportion of the lime-soda feldspars and the ferromagnesium minerals. Both of these groups of minerals are especially liable to alteration. Quartz, on the other hand, is relatively scarce. There are in the region no quartzites and argillites, the two classes of rocks which are especially indifferent to the action of the weathering processes. Certain beds associated with the lavas are composed of fine volcanic ash in which the constituent particles had never acquired a crystalline structure but were entirely glassy. These are perhaps the most rapidly altered rocks in the region, and wherever they have been encountered, even as in the eastern division at very great depths beneath the thick sheet of dacite, they are found in the form of a soft soapy or talcose rock.

The rocks of the Brito formation contain a much smaller proportion of igneous constituents than any of those in the eastern division. Hence they are in a measure free from this source of weakness. They contain, however, a large proportion of lime carbonate, and in them the weathering process consists chiefly in the solution and leaching out of this cementing material. In most of these rocks the lime forms so small a proportion of the entire mass that the bulk is not diminished or the structure altered by its removal. The rock merely changes in color from bluish gray to brown or yellow and at the same time becomes soft and porous.

Effect of Original Structure.—The original structure of many of the rocks is such as to facilitate weathering to a considerable degree. This is especially true of the basalts which are largely composed of surface lava flows and have the vesicular structure which is characteristic of such flows. In many cases it is observed that the degree of weathering in the case of basalts varies directly with the extent of the vesicular structure. The upper and lower surfaces of the flows which were rapidly cooled by contact with the underlying rocks and by exposure to the air, contain more or less abundant gas bubbles, while their central portions are relatively compact. In such cases it is found that the vesicular portions are thoroughly weathered, while the interior compact portion contains large boulders of fresh rock or continuous beds of the same. The dacite which so far as observed never has the vesicular structure of the basalt, does not show these striking differences in the degree to which its different portions have weathered. The depth of weathering in the volcanic sandstones and conglomerates naturally depends largely upon the original structure of their constituents which shows considerable variation.

Thus the conglomerate encountered at upper Ochoa is composed chiefly of pebbles of compact fine-grained basalt and is weathered only to a moderate depth. A conglomerate was encountered at lower Ochoa similar to the above, except that its constituent pebbles are largely composed of vesicular or pumiceous basalt. This difference in the composition of the pebbles is accompanied by a corresponding difference in the depth of weathering which has extended to a very great depth in case of the latter rock.

Effect of Secondary Structures.—A third important factor in determining the depth to which rock decay has gone is the extent to which the rocks have been affected by dynamic agencies with the production of secondary structures, such as folds, faults and joint planes. Of these effects jointing is perhaps the most important. It pervades all the rocks of the region, both igneous and sedimentary. The joints which intersect the igneous rocks are perhaps largely due to shrinkage on cooling. The regular prismatic jointing common in basaltic lava flows has not been observed in this region. In its stead is a system of more or less regular joints which divides the rock into large rhomboidal blocks. The less basic rocks, such as the dacite, and the volcanic conglomerates are nearly or quite free from these joints, and the manner in which they weather is therefore different from that of the basalt.

The sedimentary formations are generally very deeply fractured. In these the joints are doubtless due to the action of dynamic forces which, while they have not greatly changed the original position of the beds, have been sufficient to thoroughly shatter them to great depths. Only a few of the more massive beds of sandstone have in some measure escaped this general fracturing. Its effect is most pronounced in the less massive portions of the Brito formation. At the surface the joints have been enlarged by the weathering process, and the rock consists of a loose mass of small fragments. This condition prevails to a depth of more than a hundred feet from the surface, as shown by the boring at La Flor. One effect of the jointing of the rocks is to make it nearly impossible to obtain a core with the diamond drill. This fractured calcareous shale is the material which has been termed "telpetate" and "cascajo" in the reports of the drilling done by the Canal Company. In some cases it was observed that the cracks which intersected the rocks had subsequently been healed up by the deposition of calcite. This, however, is not general at ordinary depths.

A direct consequence of the presence of these cracks intersecting the rocks is the development of secondary concentric structures. The cracks permit the percolation to great depths of surface waters bearing the agents which are most active in rock decay. The weathering proceeds outward from these joints with the production of successive concentric layers about a central nucleus. The concentric structures which have already been described were thus produced.

Rock Decay in the Eastern Division.—As has been already pointed out there is a marked difference in the distribution of the rainfall on opposite sides of the isthmus with a corresponding difference in the character of the vegetation and in the extent and products of rock decay. It will be necessary, therefore, to consider the process and the products in the two divisions of the isthmus separately.

The eastern division is characterized by a heavy rainfall, so distributed throughout the year that there is no well-marked dry season. Hence the surface soil is never permitted to be-

come dry, and the forest litter is never removed by fires. The entire surface is covered with a dense mantle of vegetation. This consists of a heavy forest growth except where the land surface has been so recently reclaimed from swamps and lagoons that it has not yet been invaded by the forest, or that its surface is not sufficiently firm to support forest trees. Even where the forest does not extend, the smaller vegetation is extremely dense, and the surface is even more effectually protected than under the forest. It may be stated in general, however, that all of the land which rises above the margins of the extensive flood-plains and the silt-filled valleys, that is, all which is underlain by rocks older than the recent silt, is forest-clad. The canopy of foliage formed by the tree tops is so perfect that much of the light and all of the direct sunlight is intercepted, hence the smaller vegetation at the surface is not exceptionally luxuriant and only partially covers the surface.

The forest trees of this region are nearly all deciduous, but the season of shedding their foliage is different for different species; hence there is a continuous supply of forest litter throughout the entire year, and its decay not being checked by frost is a continuous process.

All rocks of this eastern division show the effects of weathering to great depth, not only the igneous but the sedimentary rocks as well. In the course of the drilling operations which were carried on in this region, a large amount of data was obtained concerning the depth to which decay has gone in rocks of various origin and composition, and also the products of the weathering. The sections which were obtained by means of the drill are so numerous that only a few typical examples have been selected for publication in detail in this report. The information obtained in all is of course embodied in the various sections which have been prepared for the use of the engineers. These sections which appear in Plates VIII to XIV will be referred to for the purpose of illustrating the statements here made concerning the process and products of rock decay.

Products of Rock Decay.—The final product of rock decay in this region is a red clay. This represents the complete oxidation of all the constituent minerals of the rock except the quartz, and the complete obliteration of the original rock structure. From this extreme the products of rock decay present all possible gradations to the perfectly fresh rock. While there are no sharp lines of demarkation between different phases of the rock weathering, the products may be conveniently, though somewhat arbitrarily, separated into three groups, namely, red clay, blue clay and soft rock. The first two differ chiefly in the degree of oxidation, and the second differs from the third chiefly in the extent to which the original structure of the rock has been obliterated. The third group itself is not sharply separated from the fresh rock but passes into it in most cases by imperceptible gradations.

Red Clay.—As already stated, in the eastern division of the region under discussion, all portions of the surface which rise above the margins of the alluvial flood-plains, are covered with this final product of rock decay.

Its appearance and doubtless also its composition vary somewhat from place to place. The bright red is varied by shades of yellow, brown and occasionally olive green, but the prevailing tint is nevertheless very generally red. The abrupt change in color between the residual clay and the adjacent alluvial clay is very striking. The latter is never red, but is always some shade of gray or blue. The only essential dif-

ference between the two clays is in the form of their iron. In the alluvium this is in the ferrous state, forming light-colored compounds. In the residual clay it is in the ferric state, and not only more highly oxidized but the oxide is in large measure dehydrated, giving the bright red color of hematite. The cause of this difference in the state of oxidation in clays which appear to be affected by the same conditions, is doubtless the different amounts of organic matter incorporated with them. As already described, the residual clay is very compact. It is never loosened by frost or by shrinkage cracks. The only means by which vegetable matter finds its way below the surface is by growing roots and insect burrows. The amount thus introduced is not sufficient to materially affect the chemical conditions within the zone of rock decay. The vegetable matter at the surface is so rapidly and thoroughly oxidized that the organic compounds which result from the process are not effective reducing agents when they percolate downward in contact with the red clay, but probably carry an excess of oxygen which is expended in the oxidation of the rock constituents below. In the alluvium, on the other hand, the vegetable matter while only rarely constituting a large proportion of the mass, is thoroughly disseminated through it and controls the chemical conditions, preventing the oxidation of ferrous compounds and reducing ferric compounds to the lower state of oxidation. Before the deposition of the alluvium which now fills the valleys of the region, the bottoms of these valleys were covered with residual clay the same as that now covering the hills. This clay underlying the alluvium and subjected to the constant downward percolation of the reducing solutions from the latter has generally, though not always, lost its red color. It is often found to be mottled with blue patches where the reducing solution has gained access to the ferric oxide.

Doubtless the proportion of silica, alumina and iron depends to some extent on the composition of the rock from which the clay was derived, but this variation is not sufficient to produce marked differences in its appearance and physical properties. The depth of this upper division is not very great, usually from ten to thirty feet. The separation between the red clay and the underlying blue clay is usually rather sharp, although in many cases there is a band of mottled clay between the two.

Blue Clay.—This division is usually somewhat thicker than the overlying red clay. While its prevailing color is blue, it varies from white to various shades of yellow and brown, depending largely upon the original composition of the rock from which it was derived. It represents the zone of complete rock decay and disintegration but incomplete oxidation. The blue color is due not to the presence of a reducing agent but to the absence of a sufficient oxidizing agent to convert the iron into the higher oxides. It generally contains more or less abundant fragments of thoroughly weathered rock which retain their original structure, and where it is derived from basalt it usually contains numerous boulders of fresh rock, the nuclei about which concentric weathering has taken place. The lower limit of the blue clay division is often more indefinite than its upper limit. By an increase in the number and size of the rock fragments, both fresh and weathered, it passes into the zone of soft rock. As will be readily seen, the point at which the division should be drawn is, to a large extent, arbitrary, since the distinction is at best only one of degree.

Soft Rock.—The red clay contains but few of

the characteristics of the rock from which it was derived, hence it is fairly uniform throughout the region. In the blue clay, also, the original character of the rock is almost entirely obliterated and it is therefore somewhat uniform. In case of the soft rock, however, in so far as it retains the original structure of the rock from which it was derived, it presents the same diversity as the hard rocks of the region. In some cases this division is wanting and the blue clay extends entirely down to the fresh rock. This is the case with the Machuca sandstone as shown in the sections 1 and 2, Plate XIV. In other cases the blue clay is thin or absent and there is a great thickness of soft rock. This is the case with the dacite as shown at Tambor Grande in sections 1 to 3, Plate X.

The material classed as soft rock represents the zone of practically complete rock weathering but of incomplete rock disintegration. The forms of the constituent minerals can usually be made out in rocks which were originally coarse-grained. The original structure is generally well preserved. In the vesicular lavas the gas cavities are nearly as perfect as in the hard rock. In the volcanic conglomerates and breccias the distinction of matrix and inclosed pebbles or angular fragments is perfectly sharp. Yet all the material included in this class can be crumbled in the fingers.

The extensive beds of fine basaltic and andesitic tuff which occur in the Eastern Divide and elsewhere are perhaps the most easily altered rocks in the region. There is some doubt as to their ever having been thoroughly consolidated, and this may account for the depth to which they are weathered. Wherever found, even under a great mass of compact, fresh dacite, the tuffs are soft and talcose, resembling a very compact, structureless clay. The principal alteration which the material appears to have undergone is hydration. It can be easily cut with a knife, and on exposure to the air it loses water and is intersected by numerous cracks. If thoroughly dried and then immersed in water it immediately crumbles to a fine, incoherent sand. This material has not been placed in the class with the soft rock although it might properly be so classed. Since the classification shown on the sections was made with a view to its practical application to engineering problems, the upper limit of hard rock does not generally correspond with the limit of rock weathering from the surface downward. The rock classed as hard usually shows more or less alteration of its constituent minerals, but not enough to affect their coherence. While this incomplete weathering does not materially affect the excavation of the rock, it becomes very important and should be carefully considered when the rock is intended for use in construction. Rock which appears to be perfectly fresh when first removed from the quarry often contains many incipient fractures, and these develop rapidly on exposure. It is probable, as will be pointed out later, that all of the tuff and a considerable proportion of the dacite in the Eastern Divide cut would develop this weakness on exposure and hence would be entirely unsuited for structural purposes.

Rock Decay in the Western Division.—Turning now to the western division the phenomena of rock decay are found to be strikingly different, and, as already pointed out, this probably depends largely on climatic differences which prevail on opposite sides of the isthmus. The most striking difference is the almost complete absence of red color in the surface soils. This change in color coincides so exactly with the change in climatic conditions that it is diffi-

cult to escape the conclusion that the change in color is due directly to climatic causes. The prevailing color in the surface soil in the region west of the lake is a bluish-gray, varying to black. It is sometimes a yellowish-gray and very rarely red. One reason suggested for the absence of the complete oxidation of the surface soil and the consequent red color is the greater amount of vegetable matter which becomes incorporated with the upper layers of the soil. As pointed out in the discussion of the climate it was shown that the surface is alternately baked and saturated with water. The numerous cracks which form during the dry season collect leaves and twigs, and when the cracks are closed up by the moistening of the soil this vegetable matter is thoroughly incorporated with the clay to a very considerable depth. It may be that it is present in sufficient quantity to combine with all the oxygen which is carried down by the percolating waters and thus prevent the oxidation of the iron contained in the underlying rocks. This reducing action of the contained vegetable matter prevents the oxidation of the iron contained in the alluvial silts in the eastern division, and there seems no reason why it should not be equally effective in preventing oxidation in the residual clays in the western division.

Another difference at once noted is the extent to which rock decay has extended. The opportunities for determining the extent of rock weathering on the west side have not been so good as for determining its extent in the eastern division, and the rocks which are there present do not afford the same variety in composition and structure. Observations are confined practically to two kinds of rock, namely, the igneous basic rock forming the large area north of the Rio Grande valley, and the rocks of the Brito formation. The basic igneous rocks do not differ essentially from those which occur on the east side, where they are covered with a great depth of red and blue clays. On the west side, however, the residual material covering them consists of a comparatively thin layer of bluish-gray clay. It is somewhat doubtful whether the thinness of this residual mantle is due to the less rapid decay of the rock or to the more rapid removal of the products of weathering. Certainly the latter factor is important, but the rate of weathering may also be very much slower, under the climatic conditions which here prevail, than in the eastern division. The blue clay appears to constitute practically the only product of decay, and the extensive zone of soft rock in which the minerals are entirely altered but in which the original rock structure remains is entirely wanting.

The clay derived from the decay of the Brito formation is quite similar to that derived from the igneous rocks, except that it contains a notable amount of sand where it is derived from the more sandy portions of the formation. Where derived from the calcareous shales it forms a blue or black tenacious plastic clay. Its depth varies from nothing up to ten or fifteen feet, depending upon the position in which it occurs. The greatest thickness is found in the level valleys where the surface is practically at base level and where the surface erosion is practically reduced to zero. Upon the steep hillsides, on the other hand, the same kinds of rocks are covered with a very scanty layer of residual soil, or it may be entirely wanting.

So far as known there is nothing on the west side which corresponds to the zone of soft rock generally represented in the sections from the eastern division. Wherever opportunity was afforded for observing the character of the passage

from the overlying blue clay to the underlying igneous rocks, the transition was found to be abrupt and the intermediate zone of weathered rock was absent.

Overlying the shales of the Brito formation there is a zone of weathered rock which corresponds in some measure with the zone of soft rock generally observed in the eastern division. Within this zone the beds are thoroughly shattered by the presence of numerous joint planes, and concentric weathering has been more or less extensively developed. The mechanical alterations which the rocks have suffered, however, are much more important and striking than the chemical changes, hence in the sections this is called the zone of disintegrated rather than decayed rock. For the purposes of the engineer, however, the distinction is not specially important. As stated above, this is the material which has been very loosely termed "telpetate" and "cascajo."

EARTHQUAKES.

Relation of the Canal Route to Centers of Volcanic Activity.—Most earthquakes for which a cause can be assigned with any degree of probability are produced either by an explosion at greater or less depth below the earth's surface or by a dislocation of the earth's crust producing a fault. The former class is confined chiefly to volcanic regions, and if the explosions are sufficiently long continued they eventually find a vent at the surface and produce an active volcanic eruption. Earthquakes produced by faulting are also to some extent characteristic of volcanic regions, but may occur remote from any scene of volcanic activity, especially in regions which are undergoing rapid elevation or depression. They are especially characteristic of regions in which the mountain-building forces are active. Earthquakes of the latter class, due to dislocations of the strata, are perhaps no more liable to occur in the vicinity of the Nicaraguan Canal route than elsewhere, and hence they do not constitute a danger which is peculiar to this region more than to almost any other in which a ship canal might be constructed. Earthquakes of the first class, however, are assumed to constitute a menace to the permanence of the canal inasmuch as the region is one of considerable volcanic activity. The question of the risk incurred from this source is certainly one which should be considered.

In the foregoing description of the topography and geology of the region the distribution of modern volcanic activity was indicated. It was shown that, while the Nicaraguan depression is occupied to a considerable extent by volcanic rocks, these belong in large measure to a former geological period, and the activity to which they owe their origin has long since entirely ceased. It was shown further that the only manifestation of volcanic activity in recent times has been along two lines of vents which have given rise respectively to the Costa Rican and the Nicaraguan volcanic ranges. The former terminates to the northward in the peak of Orosi. This volcano appears at present to be entirely extinct, and there is no authentic record or tradition of its having been in eruption since the occupation of the country by the Spaniards. Dutton described it as to all appearances a long extinct volcano; an old cone in an advanced stage of degradation by weathering and showing no traces of recent action. Squire,[1] however, speaks of it as in a state of constant activity, but he does not describe it from personal observation, nor does he give the date of any authenticated eruption.

[1] E. G. Squire, "The States of Central America," New York, 1858, p. 361.

Of the numerous volcanoes in the Costa Rican range to the southeast of Orosi only one has shown any activity within historic times. This is Irazu, near the center of the range, which was last in eruption in 1726. As described by Hill, "the entire crater occupies but a relatively small portion of the great mountain mass which it caps and is apparently a later parasitic summit growth upon a much older mass."[1] It is evident that the eruption which gave rise to the present conical summit of Irazu is an expiring phase of the activity which produced the massive mountain range.

The Nicaraguan range terminates to the southward in the twin peaks of Madera and Ometepe, occupying the island of Ometepe. The interval between the northern terminus of the Costa Rican range and the southern terminus of the Nicaraguan range is about thirty miles, and between these points passes the sailing line of the canal in Lake Nicaragua. Madera may be regarded as extinct. There is no tradition of its having shown activity, and its summit has been greatly modified by erosion, indicating that there have been no eruptions for a very considerable time. Ometepe is quiescent. It manifested a slight activity in 1883 when there was an eruption of lapilli with explosions of moderate violence. At present the only sign of activity consists in numerous fumeroles from which steam and sulphurous gases escape. While no eruption of Ometepe appears imminent, there is no certainty that its activity has entirely ceased, although the indications are that it is on the wane. Mombacho has been extinct for a long time. Its last eruption was probably one of the explosive type and destroyed its conical summit. Masaya was in eruption in 1858, but the eruption was not accompanied by explosion, simply consisting of the welling up and overflow of fluid basaltic lava. Momotombo at the northern end of Lake Managua shows signs of moderate activity. It is not at present erupting solid material, but throws off great volumes of vapors which form a black cloud over its summit. Steam and other vapors are escaping from several craters to the northward of Momotombo, but from none of them are any lavas or lapilli being extruded.

It is thus seen that the present activity of the volcanic vents which form the Costa Rican and Nicaraguan ranges belongs almost entirely to the solfataric stage which characterizes the extinction of volcanic activity. Considering the great mass of material which has been extruded from these vents in comparatively recent geologic times, it is very clear that the activity in this region is on the wane; and while eruptions will doubtless occur in the future, it can be asserted with a fair degree of confidence that these will be less violent and occur at longer intervals than in the past. It is also clear that the greatest activity at present and hence the source of greatest danger in the immediate future is not in the vents which terminate the volcanic ranges, but rather in the central portion of those ranges, that is, in central Costa Rica and in northern Nicaragua. The experience of many years proves that these regions which are the centers of greatest volcanic activity are also the centers from which emanate most of the earthquakes felt throughout the Nicaraguan depression.

Considerations Affecting Earthquake Forecasts.—The subject of earthquakes in this region and their bearing upon the problem of the canal have been studied by Major C. E. Dutton, than whom no one is better qualified to

[1] The Geological History of the Isthmus of Panama and Portions of Costa Rica, by Robert T. Hill, Bull. Mus. Comp. Zool., Vol. XXVIII, 1898, p. 230.

speak on this subject. His report accompanies the report of the Nicaragua Canal Board of 1895, and his discussion of some of the principles of earthquakes in general and their application to this particular region are quoted below.

"As regards earthquakes, it is well known that they are comparatively frequent, especially in Costa Rica and Nicaragua, and a few have been destructive in very restricted localities. It is no doubt a matter of great interest to the Canal Company; for the question at once arises whether there is not danger of serious damage from this cause to the works of construction, and of the still more serious damage of long suspensions of traffic. In order to reach some estimates of the magnitude of this danger, it may be well to state, as briefly as possible, some general considerations which must serve for a logical basis of any estimate:

"(1) The forecast of earthquakes contemplates probabilities only and not certainties. That one will happen in a particular region in a specified number of years is a probability which is great or small according to the nature of the locality and its extent. We may view such probabilities as having the nature of risk analogous to those of fire and shipwreck, with the following difference: Fires and shipwrecks are of such frequent occurrence, and have been so thoroughly investigated by insurance companies, that their probabilities under widely varying circumstances can be estimated with great precision, and the commercial value of the risk accurately determined. Earthquake risks have never been so investigated, and it is therefore impossible to assign specific numerical values to them. Nevertheless it is sometimes practicable to show that the risk is so small that it can be left out of consideration with prudence, though we may not be able to assign its precise value.

"(2) In attempting to forecast the future probabilities of earthquakes, we must assume that the future will be like the past, precisely as is done in insurance probabilities. We must assume that where they have been frequent and violent they will continue to be so, and that countries seldom visited by them in the past will be as seldom visited in the future. There is no other possible basis of reasoning.

"(3) Earthquakes originate at very different depths in the earth, rarely, perhaps never, exceeding twelve miles, and generally not exceeding three or four miles. We know almost nothing of the ultimate nature of the forces or causes which generate them; but we know considerable about the manner in which they are propagated after they have been started, and concerning their subsequent action and effects. Whatever may be the causes, we must assume that the subterranean tract or seat in which they originate occupies some space of very limited extent and contains some point which may be regarded as its center—commonly called the centrum. From the seat of origin the impulses are propagated as elastic waves in every direction, in a manner having much in common with waves of sound in the air.

"(4) The intensity or violence of these waves diminishes like that of the air, at as rapid a rate as they are propagated. At any given spot the intensity is inversely proportional to the square of the distance from the centrum.

"(5) In all destructive earthquakes, the extent of the country in which they are destructive is but a small fraction of the total area throughout which the tremors are perceptible. Ordinarily it is not far from the four-hundredth part of the area perceptibly shaken. The area in which the shocks may cause damage varying from slight to serious (but not demolition or what are usu-

ally considered destructive effects) is commonly about four to eight times as large as the destructive area, or from the fiftieth to the one-hundredth part of the area of perceptible vibration. Those ratios are only roughly approximate, and they are subject to some qualification, ordinarily not large, dependent on the depth of the centrum. They are of importance as showing the comparatively narrow localization of destructive and even damaging effects. Still, the destructive areas may in some cases be absolutely considerable, being proportional to the total energy of the shock at the centrum. The destructive area of the Charleston quake had a radius of not far from forty miles, but its tremors were perceptible at a distance of 700 to 1000 miles. Its great extent, as well as the distances at which its tremors were felt, cause it to rank among the most powerful shakes of the present century. Its intensity at the surface, however, while formidable, was not so excessive as has been experienced in some other memorable earthquakes. This was because its depth was extreme, being in all probability one of the most deeply seated of which we have sufficient knowledge to form an opinion. In striking contrast was the Casamicciola earthquake, on the island of Ischia in the Bay of Naples, in 1884. Here the destructive area had a radius of less than two miles, but within that area the violence was superlative and the havoc great. At Naples, twenty-five or thirty miles away, the shock was only a faint tremor. The depth of the Charleston quake is computed at about twelve miles, with a very moderate probable error. The Casamicciola quake had its origin at a depth, probably, of less than half a mile. Immediately over the centrum its intensity was apparently quite equal to that in the central area of the Charleston, but the total energy of the shocks was hardly one seven-hundredth part as great. These two extreme instances may illustrate the varying effects of total energy and depth upon surface intensity. The comparison is analogous to one on a smaller scale between the explosion of one hundred pounds of dynamite at a depth of one hundred feet and thirty tons at a depth of half a mile. The effects at the 'epicentrum' (point on the surface vertically over the centrum) would not differ much, but the larger and deeper charge would affect a vastly greater area, and would be felt at a much greater distance.

"There is a tendency on the part of all persons who have not made special study of the subject to entertain exaggerated ideas of the risks and dangers of what are termed earthquake countries. The terrors of the 'epicentral tract' in a great devastating series of shocks cannot, indeed, be exaggerated. The error consists in assuming them to be frequent, widespread, and typical of the country. In truth, they are rare, even in the most afflicted region, and when they do come they are destructive within relatively narrow limits only, while the country at large is shaken only by harmless quivers. It is exceedingly rare for one generation living on any spot on earth to have seen two destroying earthquakes in the same locality. In many volcanic countries there are a few spots where such catastrophes repeat themselves, though usually after very long intervals of years. These are known and can be shunned by the engineer and architect, if need be. Apart from these, all localities within an earthquake country sufficiently removed from the known centers or axis may be regarded as being in far less peril from earthquakes than from sweeping destruction by an uncontrollable fire.

"Briefly, then, my opinion is that the risk of serious injury by earthquakes to the construc-

tions proposed for the Pacific section of the canal is so small that it ought to be neglected; . . . . also, that the risks to the Atlantic section are still smaller than those to the Pacific section."

Seismic Records in the Canal Region.—On the 29th of April, 1898, there occurred an earthquake which was perceptible throughout the greater part of the Nicaraguan depression, and which was moderately destructive in the towns of Leon, Managua and Chinandaga. A commission consisting of Dr. Carlos Sapper and Dr. Bruno Miersch was appointed by the Government of Nicaragua to investigate the cause of this earthquake. This commission visited the region affected and made the ascent of numerous volcanic peaks in the vicinity of its greatest violence. They found no signs of imminent eruption in any of the craters visited, and reached the conclusion that the earthquake was due, not to a volcanic explosion beneath one of the numerous craters of the region, but to a dislocation of the strata. It is probable, as has been indicated in a preceding part of this report, that this region to the north of Lake Nicaragua has been affected by faults in comparatively recent times, and the present earthquake may be due to a further displacement along one of these old lines of fracture or to the inauguration of a new fracture. The absence of any signs of increased activity in the volcanic craters, however, is scarcely conclusive evidence that the earthquake was not due to a deep-seated explosion intimately connected with the causes of the vulcanism. It is the deep-seated explosions, those not relieved by an eruption at the surface, which probably cause the most destructive earthquakes. When a vent is formed with an open passage from the seat of the explosion to the surface, the violence of the effects is diminished, or rather it is manifested in an eruption of lapilli and lava rather than in earthquake waves transmitted through the crust to the surface.

Leon was visited by the writer shortly after the earthquake of April, 1898. The effects observed in that city were chiefly the formation of cracks in the walls and the partial destruction of buildings constructed of adobe. This material has very slight coherence and is poorly adapted to resist the strains produced by earthquake vibrations. No solidly built wooden or stone buildings suffered greater damage than the formation of a few cracks over the doors and windows. The cathedral of Leon suffered no damage except the displacement of a large globe which rested on a slender support on the ornamental façade of the building. It was concluded that if such a structure as a canal lock built on a suitable foundation, had occupied the epicentral tract of the Leon-Chinandaga earthquake it would have suffered no material damage, almost certainly not enough to interfere with its continuous use. The risk at points two hundred miles distant from the epicentrum, that is at the nearest point on the canal route, would have been entirely negligible.

The only source of possible danger from earthquakes to the eastern division of the canal lies in the Costa Rican volcanoes. Occasional earthquakes are experienced in central Costa Rica, the most violent since the occupation of the country by the Spaniards having been the one which destroyed the town of Cartego in 1841. This emanated from the neighboring volcano of Irazu and was of the shallow type with a small epicentral tract. It was only slightly destructive at San Jose, about thirteen miles farther from the source than Cartego. The much greater distance of the canal from this volcano renders the probability of an earthquake from that source extending its destruc-

tive area so far as the canal structures extremely small.

Two sources of danger to the western division of the canal are present, in Orosi to the south and in Ometepe to the northeast. As stated above, there is some doubt as to the condition of Orosi. The probability, however, is that this volcano is extinct. There are no records or traditions of destructive earthquakes having affected this region, although from the absence of large towns it is doubtful if the absence of records should be considered as conclusive evidence that such earthquakes have not occurred. The distance of this volcano from the nearest canal structures which would be liable to injury is so great that unless the disturbances were of exceptional violence the only effect at the canal line would be harmless earth tremors. The extent of the danger from Ometepe can be somewhat more accurately gaged. This volcano was regarded as extinct up to the date of its eruption in 1883. It was clothed with vegetation entirely to the summit. Some earthquakes had emanated from Ometepe before the eruption. Squire speaks of the town of Rivas as having suffered much from earthquakes previous to 1850, but gives no details of their frequency or violence. The one which accompanied the eruption of Ometepe in 1883 was only very slightly destructive even at Rivas, and at the line of the canal its destructive violence had doubtless entirely disappeared. Even with the intensity manifested at Rivas it would in all probability have been entirely harmless to such a structure as a canal lock. It is not probable that those which preceded that of 1883 were much more destructive or some record of them would have been preserved. Indeed the excellent state of preservation in which the ancient churches of Rivas and San Jorge are found is conclusive evidence that the region has not been visited by earthquakes of destructive violence for more than a century.

A consideration of the present activity in these two volcanoes, therefore, and of the available records of earthquakes in this region would seem to remove all apprehension concerning the probability of damage to canal structures by earthquakes emanating from them. If the danger from these sources, which are comparatively near, be considered so small that it may be disregarded, that from the more distant centers of volcanic activity, both to the north and the south, may be dismissed as altogether too small to merit consideration. Even if there should originate at the present centers of greatest activity an earthquake with as great violence as that which has characterized some that have wrought the most destructive effects in Peru and San Salvador, it is probable that the earth waves would there be so far dissipated before reaching the line of the canal that they would be comparatively harmless. It therefore appears to the writer that the opinion above quoted from Major Dutton is entirely correct, namely, that the risk of serious injury by earthquakes to the constructions proposed is so small that it ought to be neglected.

RECENT GEOLOGIC HISTORY.

The relation between the topography and the recent geological history of the region is so intimate that a description of the former necessarily involves some statements concerning the latter. The same is to a somewhat less extent true of the lithology. Hence in the foregoing description of the topography and of the rock formations some of the main features of the geological history have been briefly outlined. With these prerequisite facts of topography and

lithology the geological history may now be taken up systematically and in some detail.

Conditions Anterior to Tertiary Time.—As already indicated, no rocks older than the Tertiary occur in the region of the Nicaraguan depression so that there is only negative evidence as to the conditions which prevailed here during geological periods earlier than the Tertiary. In the region to the northward, in Guatemala and northern Nicaragua, the occurrence of granites and crystalline schists has been described; also small areas of paleozoic rocks. The present extent of these older formations, however, as well as their former distribution is not known. The region to the south in Costa Rica also contains older formations, but they are almost completely covered by the recent volcanic rocks so that the former extent of the land in this direction also is unknown. It is quite possible that a depression of this portion of the isthmus occurred at the beginning of Tertiary time, and that a somewhat extensive land area was wholly submerged or converted into an archipelago.

Early Tertiary Deposition and Volcanic Activity.—As indicated in the description of the Brito and Machuca formations these rocks were deposited on the sea bottom in early Tertiary time. It is assumed that during their deposition there was open communication between the Atlantic and the Pacific oceans across this portion of the isthmus, although it will be readily conceded that this conclusion is merely an hypothesis. Sedimentary formations have not as yet been traced entirely across the isthmus and there is no other direct evidence by which this hypothesis can be proven. If, however, there had been any land separating the two oceans, its rocks ought to be recognizable at the present time as distinctly older than the Tertiary sediments or the volcanic rocks which are intimately associated with them. As already stated, no such older rocks are recognized in the region of the Nicaraguan depression, and although the volcanic activity which was contemporaneous with the deposition of the sedimentary formations may have cut off the communication between the two oceans early in Tertiary time, it appears at least probable that at the beginning of that period and perhaps through the Oligocene the sea had free access across the isthmus.

The character of the sedimentary rocks indicates in some measure the conditions which prevailed during their deposition, not only in the seas in which they were laid down, but also in the adjoining lands. These conditions were somewhat shallow seas with an abundant supply of sediment alternating between sand and mud. The sediment appears to have been chiefly derived, not from a region underlain by deeply decayed rocks, but rather from unconsolidated and recently ejected volcanic material. The extremely coarse conglomerates which occur in the Brito formation along the Pacific coast and on the southwest shore of Lake Nicaragua point to the proximity of active volcanoes. The coarser material supplied by these volcanoes was transported but a short distance and shows the effect of only a moderate amount of wear. The finer material was widely disseminated and constitutes a very considerable proportion of the sedimentary formations. These contain, however, a certain proportion of clay which was doubtless derived from the residual mantle covering the older rocks which formed adjacent land areas. The conditions at certain points were favorable for the deposition of limestone. Considerable lime is disseminated throughout the entire Brito formation and is segregated in marly beds and in occasional lenses of pure limestone. The volcanic activity not only fur-

nished a large portion of the material of which the sedimentary rocks are composed, but it continued for some time after their deposition, and produced numerous dikes, cutting the beds and also the extensive lava flows which in places rest upon them. This volcanic activity appears to have been much more violent and long-continued near the axis of the present isthmus than on the west side. The region between Lake Nicaragua and the Pacific ocean, as already indicated, is occupied chiefly by sedimentary beds and by recent volcanic material. Only a few large areas and occasional dikes of intrusive rocks have been found associated with the Brito formation, and it is not certain that these ever reached the surface. While the coarse conglomerates along the Pacific coast demonstrate the near proximity of volcanoes, the indications are that the volcanic vents from which this material was derived were to the west of the present coast line. The conglomerates are confined, so far as known, to the immediate margin of the ocean, and the source of the material seems clearly to have been to the westward. The similar conglomerates which occur on the southwest shore of the lake appear to have been derived from vents to the southward and to mark the southern margin of the sea in which the Brito formation was deposited.

As stated above, the Tertiary volcanic activity was more prevalent in the region east of the lake. More than two-thirds of the area which has been examined between the lake and the Caribbean is now occupied by igneous rocks which present considerable variety in composition and structure. It is probable that the present area of the Machuca formation does not represent its original extent, but merely a region in which the volcanic rocks have failed to wholly conceal the sediments. The numerous beds of conglomerate and stratified ash associated with the lavas in the region eastward from Machuca point to the presence of standing water during the period of volcanic activity. This water in which the ejecta were deposited may have been a shallow sea from whose bed the volcanoes rose, or a series of lakes formed upon the imperfectly drained constructional surface. It is very difficult, however, to determine even approximately the conditions which prevailed during the deposition of this heterogeneous collection of formations. The difficulty is, of course, greatly enhanced by the deeply-weathered condition in which the rocks are now found.

Middle Tertiary Uplift and Erosion.—The period of deposition in this region appears to have been terminated toward middle Tertiary time by an uplift which was coincident with a suspension of the volcanic activity. The extent of the land after the uplift can only be determined in a very general way. It is probable that the Pacific coast was some distance farther southwest than at present, and there may have been volcanic peaks along this coast which have subsequently been entirely removed by marine erosion. The isthmus was very likely somewhat broader than now, although the elevation was such that any particular rock stratum was from one to two hundred feet lower than at the present time. The uplift inaugurated a period of active degradation. It is probable that the surface at the beginning of this period was, in general, broadly undulating with perhaps isolated volcanic peaks but no distinct mountain chain. The uplift was accompanied by only moderate warping and tilting of the surface, for the Tertiary beds have suffered comparatively little disturbance up to the present time. Their average dips are between ten and fifteen degrees. In general, the character of the deformation was

such as to produce a series of gentle folds whose axes are approximately parallel with the coast lines. This was doubtless accompanied by more or less faulting, although evidence of the latter is very meager. The character of the present drainage makes it evident that no structures were developed in the region sufficiently well-defined and pronounced to have a marked influence on the direction of the drainage. The stream courses, with the exceptions which have been already noted, and which will be explained later, are such as would have resulted from normal stream development upon a low, gently undulating arch.

The region now occupied by the Nicaraguan depression appears to have been originally the lowest and narrowest portion of the isthmus; hence its surface was more nearly reduced to base level during this degradation period than that of the broader portion to the north. A somewhat perfect peneplain was developed along its margins, and broad base-leveled valleys were extended well back to the divide in which there were numerous low, broad gaps. Although the position of the coast lines at the beginning of this period is not easily determined, their position at its conclusion may be made out with a fair degree of probability. The Atlantic coast was perhaps about where it now is or possibly a little farther east than at the present time, for although it has subsequently been moved westward by submergence and by marine erosion, it has also been considerably extended by emergence and by deposition, so that its oscillations have about balanced each other. The Pacific coast, on the other hand, differed materially in outline from the present. As already indicated, Lakes Nicaragua and Managua then had no existence, and the coast line occupied a position indicated by one of the lines on the accompanying sketch map, Plate II. The second line is intended to represent the position of the coast at a somewhat later period.

Post-Tertiary Elevation and Gorge-Cutting.—The middle and late Tertiary time as indicated above, was occupied by a period of erosion with the reduction of much of the region to the condition of a peneplain. In the late Tertiary or Pleistocene the region was again elevated, this time probably without deformation of its surface, although there may have been a slight arching of the isthmus on the northwest-southeast axis, and possibly also an arching on a subordinate axis west of the present lake basin. The total elevation was probably between 200 and 300 feet. The immediate effect of this uplift was to stimulate the streams to renewed activity. They began at once to trench the peneplain and the broad base-leveled valleys which they had formed in the preceding period. The effect of the uplift was necessarily first felt in the lower courses of the streams and their valleys were there first lowered to the newly-established base level. Thence the deepened channels were cut backward toward their headwaters. In the valley of the river which occupied the present position of the San Juan from Castillo eastward various phases in the process of reduction were present. In the lower course of the stream a broad valley was developed with only a few isolated remnants of the former plain remaining. This extended upward as far as Tambor Grande. From Tambor Grande to the Boca San Carlos the valley was rather broad, but the adjacent hills retain distinct evidences of the former peneplain, and wherever the rocks were unusually hard the valley of the stream was correspondingly restricted. Between the Boca San Carlos and the Continental Divide, which was then near the present position of Cas-

tillo, the stream was comparatively small and flowed in a narrow gorge. Its channel was cut down to a rather low gradient backward to the present position of the Machuca rapids. At this point was the junction of three branches, probably of nearly equal size, occupying the valleys of the Infiernito, the Machuca and the present San Juan.

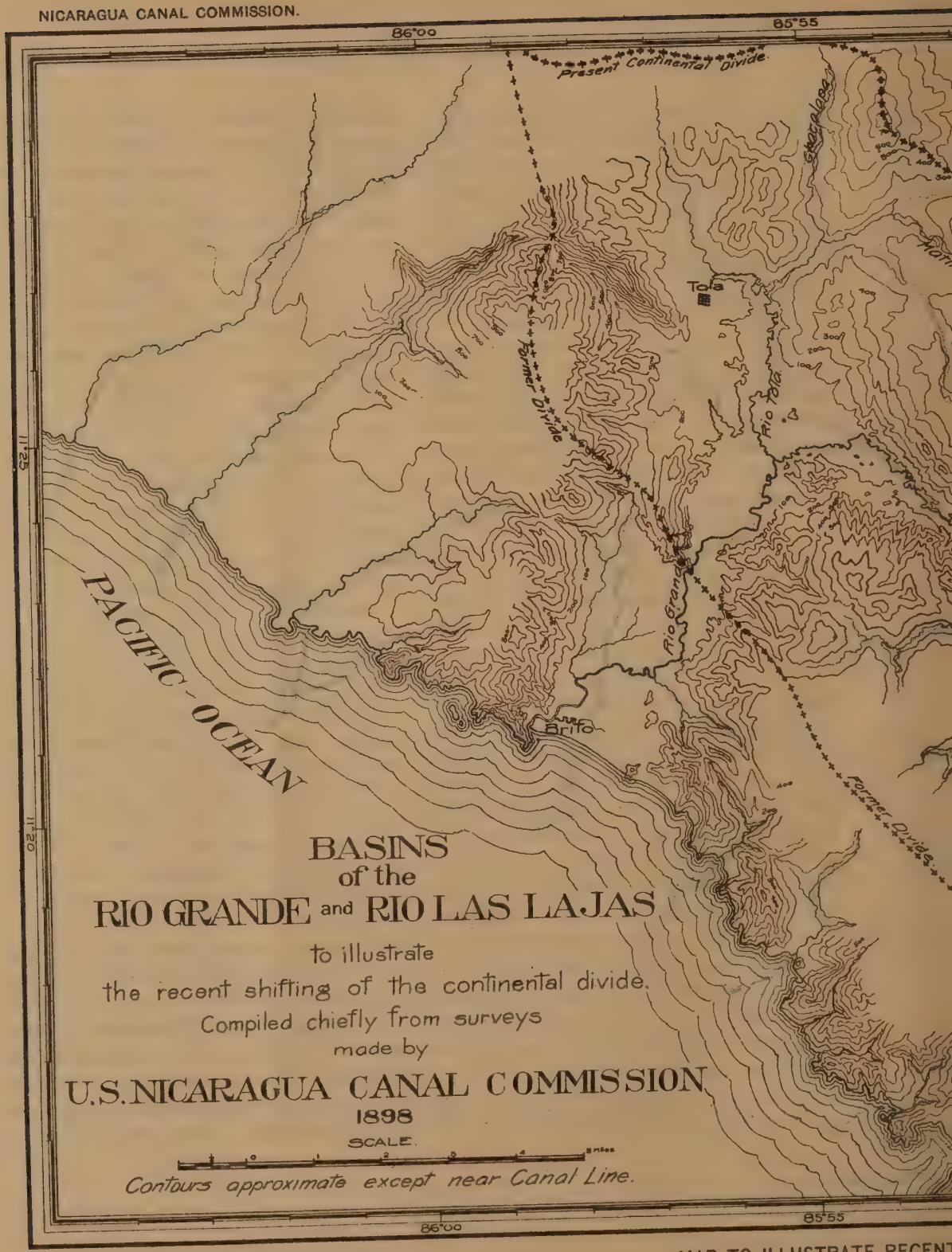
The tributaries of this river also cut down into the old valleys, and the extent to which they succeeded in lowering their channels varied with their position and size. Naturally those nearest the mouth of the stream were earliest stimulated to renewed activity by the lowering of the trunk stream into which they flowed, and hence these had the longest time in which to effect the lowering of their own channels, while those nearer the headwaters of the trunk stream were not materially affected until late in the gradation period. Thus the tributaries of the San Juan as far up as the San Francisco have lowered their channels below their old base level, if not entirely to their headwaters, at least well back toward them. Beyond the San Francisco the upper portions of the tributaries are found still flowing at the level of their old valleys, which they have not as yet had time to completely dissect. Excellent examples of this immature drainage are seen in the basin of the Machado and with increasing frequency from that point westward to the Toro rapids. Thus the Machuca and Bartola are rapid streams, still actively corrading their channels almost down to their junction with the San Juan.

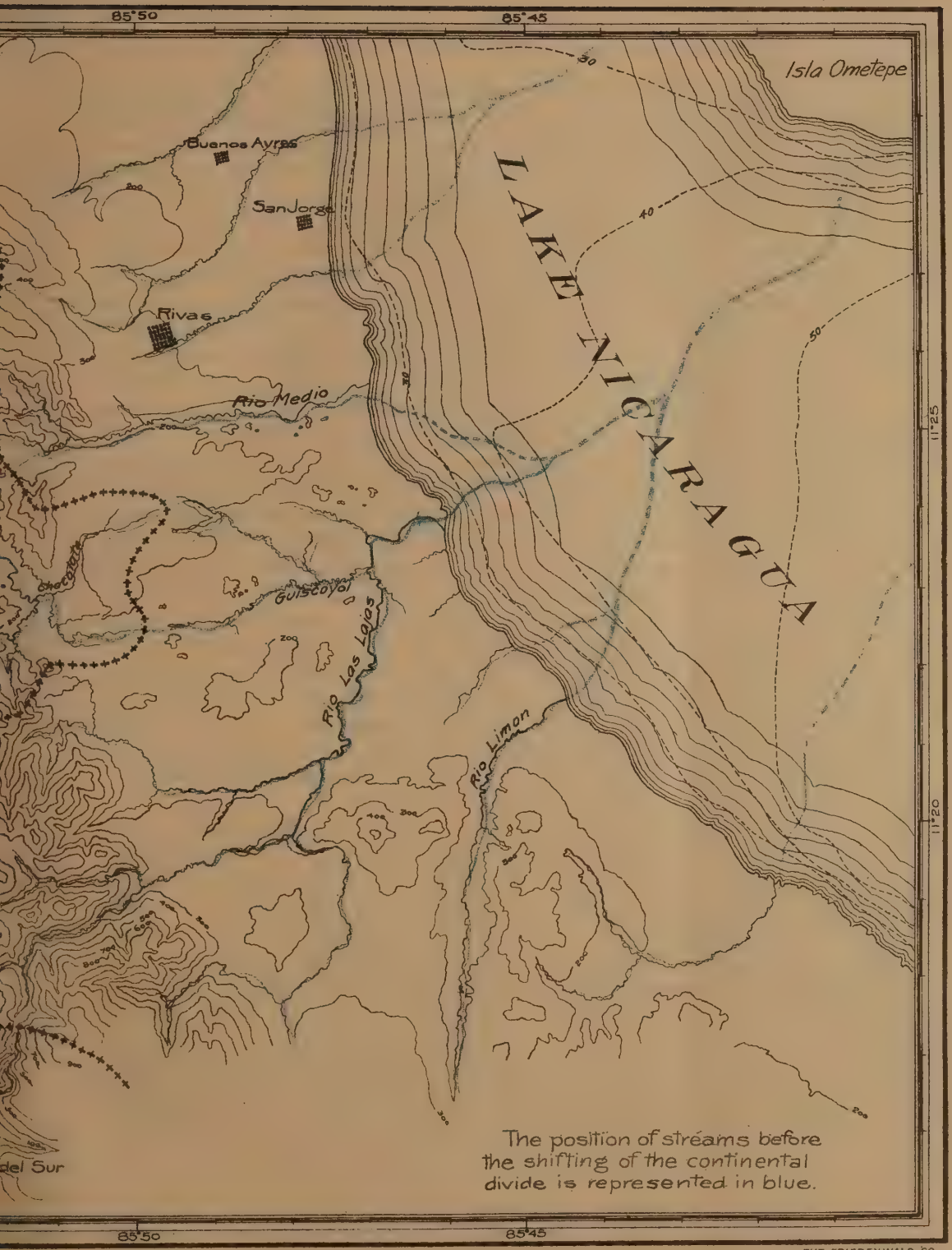
The stream which occupied the upper portion of the San Juan valley, as indicated above, headed upon the Continental Divide in the vicinity of Castillo, and receiving as tributaries the Rio Frio and other streams now emptying into the lower end of the lake, flowed northwestward to the head of a bay in the vicinity of the island of Madera. This stream, like the other, was stimulated by the uplift and rapidly cut its channel backward, dissecting its old valley well up toward the Continental Divide. This old channel, now drowned by the waters of Lake Nicaragua, has been traced more or less continuously from the vicinity of Madera southeastward with gradually decreasing depth to the vicinity of the Balsillas islands. It may very likely have extended beyond this point, and its upper portion have been subsequently filled by the sediment carried into the southern end of the lake, chiefly by the Rio Frio.

The cape which extended northwestward between the waters of the Pacific ocean and the *Bay of Nicaragua* appears to have suffered some differential uplift, its southern portion being elevated more than its northern portion. Not enough study has yet been given to the whole of this region, however, to determine with any degree of certainty the details of its recent history. Nevertheless it is known that the rivers to the southward of the Rio Grande have cut their channels much deeper than those to the northward and that some of the latter appear to have been affected but little either by this uplift or by the subsequent depression. Only the valley of the Rio Grande has been carefully studied, and it is certain that the uplift in this region was at least 200 feet.

The active wave-cutting along the Pacific coast during this and the preceding period shortened the distance from the coast to the subordinate divide on the highland forming the cape, thus rendering the length of the streams flowing in opposite directions from this divide very unequal. Those flowing to the Pacific, therefore, had a very steep gradient while those flowing eastward to the Nicaraguan depression had a

comparatively flat slope. Hence the corrasion of their channels was proportionately greater by the streams flowing directly to the Pacific than by those which reached the ocean indirectly through the Bay of Nicaragua. The former group, of which the stream occupying the lower portion of the present Rio Grande valley is the best studied example, cut their valleys well down toward the new base level nearly up to the divide; while the inner portion of the peneplain occupied by the eastward flowing streams was scarcely at all affected, and the gorge-cutting was confined chiefly to their lower portions, which are now occupied by the waters of the lake. It is true the main trunk stream entering the head of the bay cut its channel backward well toward its headwaters, but the tributaries from the southwest cut only shallow trenches in the outer portion of the Rivas plain and none at all in its inner portion. The relations of coast lines and divides which prevailed at this period are represented on the outline map, Plate II, while the former drainage, together with the present drainage and relief, are shown on the map forming Plate VI. The divide between the streams flowing to the Pacific and those flowing to the bay, which after the bay had been converted into a lake became the Continental Divide, is shown by the broken line near the Pacific coast. The length of the streams flowing in opposite directions from this Divide is seen to be very unequal. The inequality in length is so great that before the acceleration in corrasion could be felt half-way up the courses of the longer eastward flowing streams it had caused a deepening of the entire channels of the shorter Pacific streams. With such advantages the shorter streams began an active conquest of drainage area from those less favorably located on the east of the Divide. The result was that at one point where the advantages of the Pacific stream were most decided, the divide between contending streams was pushed eastward and successive portions of the eastern drainage were diverted to the Pacific. The rapidity with which different portions of the divide were shifted eastward depended largely on its relative height and the length of the contending streams. The conditions were evidently most favorable nearly opposite the end of the bay, probably because the soft sedimentary rocks here extended entirely across from the ocean to the bay, while to the north and south there were considerable areas of harder igneous rocks. Hence the surface had here been well reduced in the preceding period and was favorably circumstanced for further rapid reduction. The stream which suffered diversion earliest appears to have occupied the present position of a portion of the Tola, the upper Rio Grande, the Guiscoyol and the lower Lajas. This stream was probably five or six times the length of its opponent on the Pacific side, so that the same fall from the divide was distributed over a correspondingly greater distance, and hence had relatively much less than a fifth of the efficiency of the shorter stream. The eastward flowing stream had in the preceding period developed a rather broad valley, the upper portion of which lay between the main divide and the hills bordering the Rivas plain. The remnants of this base-leveled valley are found in the upper Tola basin, while the lower portion of that basin is very perfectly reduced to the present base level, only the uniform summits of a few rounded hills suggesting the former existence of a plain at a higher level. In the upper Rio Grande basin the Rivas plain can be traced from its typical development at the present Continental Divide westward through the increasing degrees of dissection to


86°00
85°55
Present Continental Divide
Former Divide
Tola
Rio Tola
Rio Grande
Brito
PACIFIC OCEAN
Former Divide
11°25
11°20
BASINS
of the
RIO GRANDE and RIO LAS LAJAS
to illustrate
the recent shifting of the continental divide.
Compiled chiefly from surveys
made by
U.S. NICARAGUA CANAL COMMISSION
1898
SCALE.
Contours approximate except near Canal Line.



OF THE CONTINENTAL DIVIDE.

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LITHOGRAPHERS.
BALTIMORE, MD

the summits of a few hills nearly down to the Tola. The inference, therefore, that the remnants of the plain observed in the upper Tola and in the upper Rio Grande valleys were originally portions of the same base-leveled plain, is fairly well established. Accelerated by the lowering of its outlet the diverted Tola has itself made considerable progress in the conquest of drainage formerly belonging to the eastward flowing streams. It has diverted branches both of the Gonzales and Medio, the reversed streams now forming the Chacalapa and Matinga, and leaving low gaps in the present Continental Divide. The Guachipilin now flowing into the upper Rio Grande, formerly found an outlet eastward to the Medio, and its deserted valley is the point for crossing the divide selected by Commander Lull for his canal route. The latest diversion has evidently been the Guiscoyol, which was perhaps the largest stream in this region flowing eastward. Its source, now forming the headwaters of the Rio Grande, was in the high hills which border the lower Rio Grande valley. The Rio Grande is thus seen to have a composite course, which, considering the Cascabel as its head, now makes a nearly complete circuit before reaching the sea.

The recently deserted gap between the diverted upper Rio Grande and the beheaded Guiscoyol is a broad shallow valley, its highest point being 154 feet above sea level. It is occupied during the wet season by a swamp from which the water appears to flow in both directions. That flowing toward the lake occupies a shallow channel evidently once the bed of a larger stream, while that flowing west soon finds itself in a narrow, sharply cut ravine with rapid descent to the rather deep channel of the Rio Grande.

The process of diversion above outlined was inaugurated at the beginning of the high-level period now being considered, but it doubtless continued during the succeeding period after the formation of the lake. It is evident that the process is still going on and that the Continental Divide is now moving eastward at a rate which may be regarded as extremely rapid compared with most drainage changes and, with the decided advantages possessed by the Rio Grande, it is somewhat surprising that the latter stream has not already tapped the lake.

Recent Depression and Alluviation.—The process of gorge-cutting which characterized the period of high level just described was terminated by a depression of the region, amounting to a little more than half the elevation which had inaugurated the preceding period. The effect of the depression was to drown the lower portions of the river valleys, converting them into tidal estuaries. At first the depression affected only those portions of the river valleys which were brought below sea level, while in the upper portions the deepening of the stream channels continued as actively as before. The waste from the land, however, instead of being carried out to sea and distributed by littoral currents began at once to shoal and fill up the heads of the estuaries. With the consequent lengthening of the streams their beds were raised and consequently the influence of the depression was extended up their valleys at a rate corresponding to the extension of their lower courses. It is probable that the depression of the surface was comparatively slow, and the filling of the estuaries may have very nearly kept pace with their formation. As soon, however, as the depression of the land was at any point slower than the filling of the estuary, the influence of the depression would proceed upstream at a rate de-

pending upon the extension of the lower course of the river.

The depression of the land appears to have been accompanied by a moderate local warping of the surface. This warping may have affected the entire isthmus, but the means of detecting it are not at hand except in the western portion. The Rivas plain has evidently suffered a gentle tilt to the northeast and it is more than probable that this tilting was accomplished during the depression of the land surface. It will be recalled that the Rivas plain is a plain of degradation formed by the action of streams flowing near base level. A plain formed in this way must necessarily be nearly horizontal, but the present Rivas plain has a slope to the northeast of about eight feet to the mile. This is manifestly greater than the gradient of streams forming a base-leveled plain. It is considerably greater than the gradient of the present streams which cross it. The latter, emerging from rather deep, narrow gorges in the residual hills to the southwest, cut narrow channels in the inner portion of the Rivas plain. These channels in some cases have a depth of sixty feet or more. They gradually decrease in depth toward the outer margin of the plain, the unequal slopes of the stream bed and the peneplain surface bringing them together at the lake margin.

Accompanying the depression of the land which inaugurated this period was a renewal of the volcanic activity of the region. It is possible that the vulcanism and the depression may be intimately related as cause and effect, or may be both the effects of a common cause. However this may be with regard to the depression of the region as a whole, it is more than probable that the observed deformation of the surface is due directly to the volcanic activity. This activity was manifested along two lines of vents, forming the lines of volcanic craters whose topography has already been described. The southern series of vents, forming the Costa Rican volcanic range, broke out within a land area and possibly upon a somewhat elevated plateau. These volcanoes have obliterated the pre-existent topography and built up a massive mountain range. The northern series of vents forms the Nicaraguan volcanic range. Between the nearest peaks of the two ranges, Orosi to the south and Madera to the north, there is a gap of about thirty miles. However closely the two ranges may be associated in the causes which led to the extrusion of their lavas and in the character of their lavas, they are entirely distinct at the surface and are separated by sedimentary and igneous rocks belonging to an earlier geological period. As seen from the map (Plate II) on which the former position of the Pacific coast line is shown, the volcanic vents which formed the Nicaraguan range broke out upon the sea bottom and extended nearly parallel to the western coast. The northern vents of the group were much more active and have given rise to a somewhat continuous mountain chain and also to the extensive Jinotepe plateau.

Formation of Lake Nicaragua.—The position of these volcanic vents with reference to the coast line was such that when their ejected material had reached the surface of the sea it formed a barrier across the Bay of Nicaragua. This barrier was built gradually higher by successive eruptions, and since in the area behind it precipitation was greater than evaporation, the waters rose above sea level and doubtless escaped westward over the barrier during the occasional periods of quiescence in the volcanic activity. As the surface of the barrier was raised by successive additions of volcanic ejecta, the surface

of the impounded waters was raised to a height probably somewhat above the present elevation of Lake Nicaragua. The lake thus formed occupied not only the position of the former bay but flooded the basins of the tributary streams. Its surface finally reached the lowest point in the Continental Divide where a westward-flowing stream headed against one which occupied the present position of the San Juan. When this point was reached, the intermittent escape of the impounded waters across the volcanic dam to the westward was changed for a permanent outlet to the eastward. The gap, when first discovered and overtopped by the rising waters, was doubtless underlain by deeply weathered rock and residual clay. This must have been very rapidly cut down by the escaping waters until the underlying hard rock was reached, when the permanent level of the lake was established which it has retained practically unchanged to the present time.

It is quite possible that the gaps through the Continental Divide to the east and through the divide across the western strip of land, between the former bay and the Pacific ocean, were so near the same level that the lake had for a short time an outlet both to the Atlantic and the Pacific.

An examination of a portion of the Rio Grande gorge possibly throws some light on this point. From the point where the Rio Grande turns abruptly to the northwest in the reversed channel of the streams which formerly flowed eastward, for a distance of four or five miles to the point where the gorge opens out to the alluvial plain bordering the lower river, there is an old channel which has been partially silted up by the present river. The stream only occasionally touches the rock walls of the gorge on the convex sides of its meanders. At the same time it nowhere departs wholly from the old channel, that is, it nowhere has the character of a superposed stream. It is evident that the present stream is smaller than one which excavated and formerly occupied this valley. There are three ways in which the present conditions might have been brought about:

1. The present valley might have been occupied by a stream which was once larger than at present, but which has suffered a partial diversion of its headwaters by capture through the encroachment of a neighboring stream. This possible explanation, however, is not applicable in this case, since the Rio Grande is itself a growing stream and is constantly adding to its drainage area, and hence to its volume by encroaching on the basins of its neighbors. There is no evidence from the arrangement of the drainage in this region that the Rio Grande has ever lost any territory in this way.

2. The former volume of the Rio Grande might have been greater by reason of different climatic conditions which at some former time gave the region a greater rainfall than it now has. There is no direct evidence in favor of this hypothesis. So far as known there is no evidence whatever that the rainfall has ever been greater in this region than it is at the present time. On the contrary, if a greater rainfall had been the cause of the old valley this condition would have been general in its effects and all the streams of the region would show the same evidence of greater volume in the past. So far as known, however, the Rio Grande is exceptional in this respect.

3. The third possible explanation is that the lake may have found an outlet for a short time by way of the Rio Grande valley. As pointed out above, the lake rose behind the barrier formed of the volcanic ejecta until the level of

the impounded waters reached the lowest gap in the Continental Divide where they spilled over and escaped by way of a river channel leading eastward to the Caribbean. Now the material forming the gap in the Divide must have been residual clay and deeply weathered rock, material which would be rather readily removed by the corrasion of the escaping waters. Also a study of the present river gorge where the Continental Divide formerly existed shows that the channel has here been considerably lowered. It does not seem at all improbable, therefore, that the lake for a short time may have been fifty or more feet higher than now with reference to the surrounding country. But if it were raised fifty feet its waters would escape by the Lajas-Grande gap westward to the Pacific. It seems possible that, when the waters of the lake were first raised by the growing barrier to the northwest, they found two gaps at approximately the same altitude and for a time escaped in part eastward to the Atlantic and in part westward to the Pacific. Active corrasion of the two outlets began at once. The gorge of the Rio Grande was excavated, but the gap in the main divide in the east was at first in less resistant material and was consequently cut down the more rapidly. By the time hard rock was reached in this gap the waters had been entirely withdrawn from the western outlet. The eastward tilting of the region west of the lake may have continued well into this period and have been in some measure instrumental in finally turning the outlet to the east.

It is possible that at first the gap in the main divide to the east was so much higher than the one to the west that all the water escaped by the latter; that the backward cutting of the eastward flowing stream lowered a gap in the divide and by reason of the less resistant material of which it was composed diverted at first a part and finally all the waters of the lake to the eastward. This is only a modification of the third hypothesis and does not affect the main point, namely, that for a longer or shorter period the lake had two outlets, one by the Lajas-Grande gap and the other by the valley of the present San Juan.[1]

This modification of the hypothesis removes one of the most serious objections to the above-stated theory for the origin of the lakes. An examination of the region which it assumes to have been occupied by the Continental Divide leads to the conclusion that the lowest gap in the Divide was probably more than fifty feet above the present river. An elevation for the present divide above the San Juan at Castillo of one hundred feet or possibly more would accord better than an elevation of fifty feet or less with the topography and drainage of the region and with the characteristics of divides in general. And it is by no means impossible that the backward cutting of the eastward flowing stream should lower the gap fifty or seventy-five feet in residual clay, while the outlet of the lake was cutting the four or five miles of rock gorge now occupied by the Rio Grande.

Subsequent Modification of the Lake.—The original outline of the lake formed behind the barrier of volcanic ejecta was probably quite different from that of the present lakes. The

[1] In support of the above theory for the origin of Lake Nicaragua some evidence may be deduced from its fauna. As is well known, the lake contains many sharks and sword fish. These characteristically marine forms have evidently occupied a body of salt water which has been separated from the ocean by a barrier they were unable to pass, and subsequently so gradually freshened that they have been able to adapt themselves to the changed conditions. Of special significance is the fact communicated to the writer by Dr. Theo. Gill that the sharks of Lake Nicaragua are specifically identical with those found in adjacent portions of the Pacific, but distinct from those found in the Caribbean.

subsequent modification has been due to several agencies. The continuation of volcanic eruptions has doubtless very much contracted the northwestern portion of the depression. It is probable that the original depression was occupied by a single lake which extended northwestward beyond the present limits of Lake Managua. Later eruptions encroached upon this portion of the lake basin, and finally a flood of volcanic ash and mud was carried entirely across the depression, forming a barrier which cut off the upper portion of the lake, raising its surface between thirty and forty feet above the surface of the larger portion to the southeast. The strip of land separating the two lakes is a nearly perfect plain composed of partially consolidated volcanic tuff. The Tipitapa river which forms the outlet of Lake Managua, crossing this barrier has cut its channel backward nearly to the upper lake. It falls about thirteen feet within less than half a mile of the point where it emerges from Lake Managua. In a very short time, therefore, unless the backward cutting of this stream is arrested, the level of Lake Managua will be lowered to the extent of thirteen feet. The original outline of Lake Nicaragua has further been slightly modified by the recent volcanic eruptions in the vicinity of Madera and Ometepe and perhaps also of Mombacho. The northeastern side of the latter volcano appears to have suffered an enormous landslide, which has pushed before it a great mass of earth and rock. This now has a peculiar hummocky surface and forms a long point projecting into the lake and a large number of small islands.

The outline of the lake has further been modified by the action of the waves. The trade winds produce a nearly constant surf on its western side and this has accomplished considerable erosion at certain points. The wave action has probably cut a shelf into the adjoining plain entirely around this portion of the lake, the extent of the shelf depending upon the character of the rocks which were encountered by the waves. In the region south of Madera bold headlands are formed by masses of hard igneous rocks which tend to protect the less resistant rocks between. At some points the steeply inclined sedimentary rocks contain certain beds of sandstone which are much more resistant than the mass of the formation, and these form parallel ledges which extend into the waters of the lake in some cases a mile or more, the softer rocks between having been removed by the wave action to a considerable depth. Some estimate may be made as to the extent of the wave-cut terrace along the lake shore west of Ometepe from the height of the cliff. The Rivas plain has an average slope of about eight feet to the mile, and it is assumed that this plain extends to the eastward under the waters of the lake. If it retains the same slope a cliff 24 feet in height would represent a terrace at least three miles broad. It is probable that the wave-cut terrace varies between two and four miles along this portion of the shore. From Zapatera northward to Granada the wave-action is more efficient than on any other portion of the lake by reason of the greater sweep which the prevailing winds and waves possess. Since the shore is here composed of only partially consolidated volcanic ash, the modification of its outline, due to wave action, has been very considerable. It is probable that this action has severed Zapatera from the mainland and that the many islands surrounding it were originally portions of that volcanic cone. They probably represent the more resistant lavas from which the softer materials have been washed away.

The modification of the northeastern shore of

the lake by wave action has been extremely slight. This portion of the lake shore is without a beach, and only rarely is there any considerable surf. Hence only a few points which project well out into the lake show any effect of wave action.

The material eroded by the waves from the western shore has been carried northward by the action of the waves and deposited in the upper end of the lake. A bar has been built across the point of the lake enclosing a broad, shallow lagoon behind it, and the outlet of Lake Managua has been pushed northward by the sand drift well toward the northern margin of the valley.

The third way in which the outline of the lake has been modified is by the building out of its shores by material brought down by tributary streams. The effect of this is seen almost exclusively along the southern and eastern shores. Elsewhere the constant surf and consequent littoral currents have been sufficient to distribute the sediment as rapidly as brought down by tributary streams, so that not only have no additions been made to the lake shore but the new material added has not been sufficient to compensate for the wave erosion. When the waters first occupied the depression behind the barrier to the northwest, the outline of the lake must have been quite irregular, since it filled a river basin, some portion of which had rather strong relief. Much of its basin occupied a region which had been comparatively well base-leveled, but its waters also extended up the valleys where the divides remained in strong relief. Many shallow estuaries were thus formed, and these have subsequently been entirely filled with sediment by the streams entering their heads. The most extensive filling was at the southeastern end of the lake where the largest tributaries enter it. It is evident that the broad swampy plains bordering the Rio Frio and the upper San Juan were originally portions of the lake which have subsequently been silted up.

Reference has been made to the effect of the Costa Rican volcanoes upon the drainage of the Nicaraguan depression. The series of eruptions which give rise to this range probably broke out in a land area on which there was a well-developed system of drainage, similar to that north of the present San Juan valley. This drainage system, however, was entirely obliterated, and a new divide was established following the line on which the vents were located. The effect of this was to greatly enlarge the drainage area of the San Juan. The streams which were developed on the northern sides of the rising volcanoes were compelled by the slope of the region to flow northward, where they intersected the heads of the small tributaries of the San Juan. This resulted in the composite courses of the present southern tributaries of the San Juan, which has already been pointed out and explained. The eruptions of the Costa Rican volcanoes not only added to the drainage area of the San Juan, but also furnished its southern tributaries with an abundant supply of unconsolidated material.

PHYSIOGRAPHY OF THE SAN JUAN VALLEY.

In the foregoing account of the topography of the region and its recent geological history many of the peculiarities of the San Juan river have been referred to or partially described. This river and its valley, however, bear such an intimate relation to any canal scheme that a somewhat more explicit account should be given of its peculiarities.

Physiographic Subdivisions of the River and Valley.—Considered from any point of

view, either with reference to the history of its development, the present character of its channel and banks, or the problem of utilizing it for a canal route, the San Juan river falls naturally into three sections. Starting from the point where it leaves Lake Nicaragua the first extends to the head of the Toro rapids, the second from the head of the Toro rapids to the mouth of the San Carlos river, and the third from the mouth of the San Carlos river to the sea. These three sections will be taken up in order, and their peculiar features pointed out in some detail.

The Upper Division.—The distance from the lake to the head of the Toro rapids by the river is about twenty-seven miles. In this distance the river receives a number of tributaries, but none of any size, unless the Rio Frio be regarded as a tributary of the San Juan. The Frio enters the latter at the point where it leaves the lake, and its mouth is separated from the lake only by a narrow tongue of swampy land which is submerged at high water. In this upper section the San Juan river has a moderate current and a considerable depth. Its banks are low and swampy except where its meanders bring it against the foot of one of the numerous hills which rise above the alluvial plain. It is evident that the lake formerly extended down to this point and considerably beyond, and that a large amount of territory has been reclaimed from the waters of the lake. The ordinary method by which lakes are obliterated is by the filling from their upper ends and by the cutting down at their outlets. In this case, however, a part of this process is exactly reversed. The lake is being filled most rapidly from its lower end. This filling is manifestly accomplished not by the water which comes from the lake, since this is practically clear, but by the tributaries which enter this lower portion. The present river channel does not necessarily coincide with the position of the river which formerly occupied this basin. Its present position is dependent upon the relative amounts of sediment brought down by the tributaries upon either side. If the Castillo and Toro rapids were cut back and the channel of the river permitted to sink through the alluvium, forming the greater part of its banks and bed, upon the old land surface which the alluvium conceals, it would have the characteristics of a superposed stream. At numerous points where its present channel does not follow the old channel, it would discover hard rocks in its downward cutting. In its present condition this may be described as a *residual river channel*, that is, a broad arm of the lake has been gradually constricted by the addition of sediments on its margin, and all that remains is the narrow river channel kept open by the current of the water flowing from the lake. To make a navigable canal it is evident that the channel of the river can be followed the greater part of this distance, the material to be excavated in order to obtain the requisite depth being alluvial silt and sand. At certain points, however, the river in its meanders impinges upon the hills which border the valley or rise above its level surface, and here if the channel of the river were followed it would be necessary to excavate in rock. Knowing the origin of the alluvial plain, it is evident that at such points, by shifting the line away from the hills a short distance, the surface of the rock will pass below the excavation line of the canal and the latter will be entirely in alluvium. The recognition of this point will effect a very material saving in the building of the canal, and at the same time will improve its alignment.

The Middle Division.—The second section of the river extends from the head of the Toro

rapids to the mouth of the San Carlos. Its essential characteristic is the rapid fall of the river and the narrow valley in which it flows. The Toro rapids which retain the lake at its present level are not formed by a solid ledge of rocks crossing the valley, but by boulders, sand and clay. It is some distance below the Toro rapids that the rock is first found crossing the valley.

It appears that, when this arm of the lake extended down to the Continental Divide, it received a rather large and swift tributary, the Rio Sabalos, near its head. The sediment carried by the Sabalos, consisting of clay, sand and boulders, was deposited on reaching the quiet water of the lake. A delta was thus formed, which extended across this arm of the lake, forming a shoal. As the river channel sank in the gap across the Divide, the latter became lower than the surface of the Sabalos delta, and the crest of the dam which retained the surface of Lake Nicaragua moved westward from its original position on the Divide to the present position of the Toro rapids. It is evident that the dam formed of this unconsolidated material is only very temporary, and that the backward cutting of the river channel, unless artificially checked, will soon lower this barrier and eventually affect the level of the lake.

It is difficult to determine exactly the position of the old divide. It undoubtedly crossed the valley of the present San Juan below the mouth of the Poco Sol. That stream has evidently inherited the lower portion of its course from a tributary to the stream flowing northwest. The Santa Cruz also probably belonged to the western drainage. The general course of the Bartola, on the other hand, indicates that it belonged to the eastern system. Hence the divide was probably between the Bartola and the Santa Cruz. It may have been at the present Castillo rapids, although it is probable that the rapids would show some recession due to erosion since the lake was formed. This, however, might be comparatively little by reason of the character of the rocks, and the fact that the river at this point carries comparatively little coarse sediment and hence is relatively inefficient in corrading its channel.

From the head of the Toro rapids to Machuca the river channel consists of rather long quiet reaches separated by rapids. The total fall in this section is about forty feet, or an average of about two feet to the mile. Of this fall all but about six feet is accomplished by the numerous rapids. Between the Bartola and Machuca creeks rapids appear to be due to the unequal hardness of the underlying rocks, and their position is probably, in large measure, permanent, the intervening quiet stretches being located upon softer rocks which are worn down by the moderate current more rapidly than the harder rocks by the swift current of the rapids.

Between Machuca and the mouth of the San Carlos the river is deep and narrow and the current is generally moderate. In some places at low stages of the river it is almost imperceptible, and when the San Carlos is in flood the current in this portion of the channel may even set upstream for a time. The water has a depth varying between fifteen and sixty feet, the bottom of the channel at some points being below sea level. It is evident that the present river is flowing in a channel which had been cut when the land stood higher than now and which has not yet been filled by sediment. Where tributaries join the river they have deposited small deltas in its channel, sometimes shoaling it entirely across. But the amount of sediment delivered

to the river by its upper tributaries has evidently been no greater than its waters were able to transport, even with the moderate current which prevails in this part of the channel. It is important to note that although not enough sediment has been delivered to the river above this point to fill its old channel, the river has built up occasional narrow flood-plains. It is evident that, while the sediment was of such a character and in such quantity that it could be readily transported by the river in the unobstructed channel, it was retained by the vegetation upon the banks, and in this way served to build up the surface of the flood-plains.

The Lower Division.—The third section of the river extends from the mouth of the San Carlos to the Caribbean sea. With the entrance of the San Carlos the character of the San Juan is entirely changed. Above this it is a comparatively clear stream and, except at the rapids, has only a moderate current. Below the entrance of the San Carlos it is usually muddy, is shallow with a shifting sandy bed and has a uniformly strong current. Its slope is very nearly a foot to the mile in this section. The Sarapiqui is very similar in character to the San Carlos, although it is somewhat smaller. Heading in the Costa Rican volcanoes it also carries a large amount of sand which it delivers to the San Juan. Many of the smaller tributaries of the San Juan deliver practically no sediment to the main stream. The flood-plain of the latter has been built up so rapidly that they are ponded in their upper courses, and the lagoons thus made, filled with vegetation, form settling basins or filters which effectually remove all sediment from their waters. They reach the San Juan as clear streams, except that their waters are discolored by decaying vegetation. Below the mouth of the Sarapiqui the channel of the San Juan bends slightly to the northward and very distinctly follows the northern margin of the valley. This position is probably due to the more abundant supply of material furnished by the southern tributaries and to the northward drift of the littoral current in the Caribbean sea. Although, as stated on a previous page, the subsidence which permitted the San Juan and its tributaries to silt up their valleys, was probably slow, the head of the estuary formed by the drowning of the lower valleys may have extended at least as far as the mouth of the Sarapiqui. As the river extended its course eastward by the filling of the estuary and later by the formation of the delta plain, it would be continually crowded to the northward by the direction of sand-drift along the coast. This tendency became more pronounced the farther out the delta was built, and the sharp northward bend of the lower San Juan is its direct consequence. As the river channel was carried northward, this portion of the valley would be filled first and to a higher level than the southern portion. The river would thus at times find itself in a position of unstable equilibrium and would seek a new channel on the lower part of the delta plain to the southward. Thus it is probable that the river originally occupied the present position of the San Juanillo (see Plate I), flowing to the northward between the spurs coming down from the Eastern Divide and the Silico hills, the latter having previously formed a group of islands. This position was probably occupied until the coast line was approximately at the point where the San Juanillo and Deseado now unite. It then gradually deserted its northern channel for the present position of the lower San Juan. Subsequently the latter became unstable and a more favorable course to the sea was found still farther south. The recent chan-

nel of the Rio Colorado was then developed at the expense of the lower San Juan. This process is still going on, and the relative amounts of water carried by the two channels have very materially changed within a generation. Unless artificially modified, the lower San Juan will continue to dwindle and practically all the water will find its way to the sea by way of the Colorado or some more favorably located channel still farther southward.

PART II

APPLICATION OF GEOLOGIC FACTS TO ENGINEERING PROBLEMS

The foregoing account of the topography and geology of the Nicaraguan depression is written from the view-point of the geologist rather than the engineer. While it contains information which it is believed has the most direct and important bearing upon engineering problems, it also contains much which has only an indirect bearing upon the work of the engineer, and even where the connection is the most intimate, it has not generally been explicitly pointed out. It remains, therefore, in the second part, to treat the region from the view-point of the engineer, and to make explicit the application of the geologic facts to the engineering problems. Numerous profiles have been furnished to the engineers showing, so far as the information available permits, the geological conditions and the classification of materials on the various lines in excavation, and at the localities where it is planned to construct controlling works, as dams, locks, weirs, etc. Upon these profiles the estimates are based as well as the plans of the canal and its appendages. Very much fuller and more reliable information is at hand concerning certain portions of the line than others; hence the information conveyed by the profiles has a great variability in value. It is difficult to represent these differences upon the profiles themselves, and it is therefore important that a somewhat detailed statement should be made concerning the information on which the sections are based and the degree of confidence with which they should be regarded. The attempt will be made in this portion of the report to discriminate between that which is known from actual observation and that which is merely inferred.

In the foregoing chapters upon the rock formations and rock decay, as well as elsewhere throughout the report, many statements have been made regarding the character of the materials with which the engineers will have to deal, both in excavation and for foundations. No systematic statement, however, has been given concerning the classification of materials adopted and the basis for the same. The classification employed will, therefore, be explained

in detail, although some repetition of statements made in other portions of the report may be rendered necessary.

CLASSIFICATION OF MATERIALS.

All the materials in place with which the engineer will have to deal in the construction of the Nicaragua Canal, have been for convenience divided into four classes, viz.: (1) alluvium, (2) residual clay, (3) soft rock and (4) hard rock. Each class presents considerable variety in the origin and physical properties of the materials which it embraces, but the classification is a practical one and it is believed to be sufficiently detailed, at least for preliminary plans and estimates, if the following explanation is kept in view.

Alluvium.—All unconsolidated material which has been transported and deposited by streams is classed as alluvium. By reason of the recent geologic changes which have taken place in this region, a very large amount of this unconsolidated material is encountered on the canal line. As pointed out more fully elsewhere, this entire region has recently stood considerably higher with reference to sea level than now, having a much rougher topography, with comparatively high hills and deep narrow valleys. A recent subsidence of the land has submerged many of these valleys, which have subsequently been silted up. The alluvium varies considerably in composition, depending upon the source from which it was derived and the manner in which it was deposited. It varies all the way from coarse, clean-washed sand or gravel to the finest clay. It may, for convenience, be separated into three sub-classes, viz.: (1) sand, (2) silt, a variable mixture of fine sand and clay, and (3) clay silt, composed chiefly of clay with little or no sand. All three sub-classes contain variable quantities of vegetable matter.

On the west side the alluvium is derived chiefly from the wearing down of calcareous shales and sandstones, with only a few igneous rocks. It consists, therefore, chiefly of fine sand with comparatively little clay, although there is usually enough cementing material to make it quite compact. In the Rio Grande flood-plain where the alluvium fills a drowned valley, it becomes in general somewhat coarser downward, and at the surface is composed of characteristic flood-plain deposits, generally very fine, sandy clay. The present channel of the Rio Grande is from fifteen to twenty-five feet in depth, and its sides are generally steep, often nearly or quite vertical. They serve to show the capacity of the material to stand at very steep slopes. It would also probably form fairly impervious embankments.

The level land bordering the upper San Juan from the lake to Savalos consists of alluvium brought down for the most part by streams heading upon deeply decayed igneous rocks. It consists largely, therefore, of the finest clay silt, much of it containing no perceptible grit. Some fine sand is found in the river channel where it remains as a residuum separated from a large amount of sediment, the sluggish current of this portion of the river not being able to transport the heavier particles. The clay silt in this region has usually a gray or bluish color. Between Savalos and the Boca San Carlos the flood-plains are not extensive, but the alluvium of which they are composed is similar in character to that bordering the upper river. Below the San Carlos there is much greater variation in its character, since the material brought down by that stream is entirely different from any derived from the adjoining country. It consists largely

of sand, the larger grains well rounded, but the smaller ones quite angular. The prevailing color is black with a few grains of red or white minerals. The sand is entirely of volcanic origin, evidently a finely comminuted, fresh volcanic rock broken up and ejected by explosive volcanic eruptions. This sand is transported chiefly by rolling along the bottom of the river, so that only the very finest portions reach the flood-plain. It forms the filling material of the old river channel under the bed of the present stream. A section taken in the flood-plain, a little distance from the river channel, reveals fine sandy silt for a considerable distance downward, with perhaps some beds of black sand toward the bottom. It seems that as the river gradually built up its bed to preserve a normal gradient with increasing length, the deposit on the flood-plain nearly always kept it so far above the bed of the stream that the coarser sediment transported by the latter was not spread over its surface. Enough of the finer portions of this volcanic sand, however, were deposited on the flood-plain in the immediate vicinity of the river, to materially modify the character of the alluvium. Of the many tributaries of the San Juan only the San Carlos and the Sarapiqui carry volcanic sand of this character. The basins of the smaller streams are located entirely upon areas of deeply weathered rocks, and the sediment which they bear consists of the products of decay derived from these rocks. The only mineral which has withstood the process of rock weathering is quartz, and this is not found in sufficient abundance in any of these formations to materially modify the sediment derived from them; hence the outer portions of the San Juan flood-plain in which the material is derived from the sediment borne by the smaller streams, differ in character from those immediately bordering the San Juan itself. Not only is the deposition near the main stream more rapid, so that the current of the tributaries is checked and lagoons are formed, but the alluvium, consisting in one case of fine sand with a matrix of clay, is relatively much firmer than that which is composed of fine clay and vegetable matter without any admixture of sand.

The material forming the delta of the San Juan consists almost entirely of sand within a belt about four or five miles broad, bordering the Caribbean. At some distance from the coast this is overlain by a thin stratum of fine swamp mud which increases in thickness toward the inner margin of the delta plain.

The alluvium is everywhere of such character that it can be easily handled with dredges. Almost everywhere it is sufficiently solid to stand at moderate slopes, the slope of one on one probably being sufficient. In some cases, as in the Florida lagoon, special precautions may be needed to preserve the slopes. The material becomes very hard when dry, and even when it is piled up so that the water can drain off, it becomes comparatively firm. This is shown in the vertical stream banks where drainage is possible, while the same material forms a soft mud in the swamps at some distance from the stream channels. The black sand when free from clay is of course quite pervious to water and would not be suitable for banks where the water level was permanently different on its two sides. This material, however, will not be encountered beyond the site of the first lock on the proposed low-level line. It is probable that, wherever the canal is more than half in excavation, the silt will form banks sufficiently impervious to hold the required height of water without the addition of any other material. Where the head is greater than fifteen feet, it may be necessary to add a puddled

core to the bank unless the latter is made of extraordinary thickness.

Residual Clay.—The climatic and other conditions which prevail in Nicaragua are extremely favorable to rock decay, and the final product from the weathering of all the rocks of the region is nearly the same. In the eastern division this final product is red clay. West of the lake, where the climatic conditions are different, the product is a gray or black clay. The red clay represents the zone not only of complete rock decay, but also of complete oxidation of all or nearly all the constituent minerals. The complete oxidation and the accompanying red color usually extend only to a moderate depth, ten to thirty feet, while the rock decay usually extends much farther. The red clay passes, by more or less abrupt transition, into a zone of blue clay which underlies it. The latter is generally mottled with red near its contact with the upper zone. Rarely the red clay extends entirely down to hard rock. Since the rocks of this region, that is east of the lake, are almost entirely volcanic, or, where sedimentary, contain a large proportion of volcanic material, the feldspathic minerals are abundant and the resulting clay contains a large proportion of kaolin. The iron-bearing minerals are also abundant as the rocks belong to the basic igneous group, and hence the brilliant red color of the clay when thoroughly oxidized. Quartz occurs in only a few of the rocks, so that much of the clay is remarkably free from grit, tough and compact. Although it is penetrated by numerous roots and burrowing insects, the absence of frost permits it to remain more compact than any surface clay in higher latitudes. Next to the silt it will form by far the largest part of the excavation. It will make perfectly impervious embankments if some means are taken to puddle it as it is deposited, but probably if simply dumped in the bank it would be pervious to water. When water is once thoroughly incorporated with the clay, it will remain indefinitely, and the resulting mixture will probably be more fluid than the silt.

The clay on the west side differs from that on the east chiefly in the matter of color. At the surface it is almost black, but becomes a bluish-black or gray a few feet below the surface and sometimes yellow near the rock. Nearly all of the clay west of the lake which will be encountered in excavating the canal is derived from calcareous shales and sandstones. These rocks have originally contained a considerable proportion of volcanic material, probably deposited as fine dust while they were being laid down, and the clay does not differ in composition materially from the red clay on the east side. It seems to be considerably more pervious to water, however, but this, as explained on a previous page, may be due to the fact that, owing to climatic conditions, it is alternately thoroughly dry and wet.

Soft Rock.—The residual clay passes by imperceptible gradations downward into the next class of materials, which, for convenience, have been grouped together as soft rock. The clay represents the zone of complete rock weathering in which the original minerals are entirely altered, with the exception of quartz, and in which the original rock structure is also in general obliterated. The soft rock represents the zone of rock weathering in which the process is only partially completed. The most altered minerals are entirely changed and the soluble constituents are largely removed, but the structure of the rock, and some of the more obdurate minerals remain more or less perfectly preserved. The material may be soft, but is not plastic like clay.

It will be readily understood that the line separating these two divisions is, to a large extent, arbitrary. They are never separated by a sharp line, and it is sometimes a matter of opinion where the division should be placed. The rocks generally weather inward from cracks which separate the mass into rhomboidal blocks. As the weathering proceeds successive concentric layers of weathered rock break off, and if the process is not entirely complete a core of fresh rock remains at the center. These fresh cores persist longest in the case of basalt and are generally found more or less abundant not only in the soft rock, but in the residual clay as well, becoming more abundant downward until they merge with the solid rock. While the final product of the weathering of nearly all the rocks of the region is practically the same, mainly a tough, red clay, each variety of rock has a mode of disintegrating and weathering which is, in a measure, peculiar to itself. Since the original character of the rock remains to a certain extent in the zone of soft rock, the original character and the peculiar method of weathering become more important than in the consideration of the residual clay.

In the Brito formation, the calcareous sandstones and shales of the west side, the bedding is nearly horizontal, rarely dipping more than 15°, but the rocks are intersected by numerous joints which are more pronounced than the bedding planes. There are usually at least two systems of vertical joints and frequently more, so that the rocks are broken up into rhomboidal blocks which usually vary in size with the thickness of the beds. The distance between the main joints is generally about the same as the distance between the main bedding planes. Only a few of the more massive beds of sandstone appear to be continuous and unbroken by these joints. Much of the rock is a fine-grained calcareous mudstone or non-fissile shale. This is broken up into small rhomboidal blocks a few inches in diameter, and in the zone of soft rock these are weathered in such a manner that concentric flakes split off from the blocks and, when exposed, they crumble entirely down to the center. The weathering is produced by the leaching of the soluble constituents, chiefly lime, and the decay of feldspathic minerals. The disintegration of the rock, however, which is due to jointing, is a much more marked feature than the rock decay. This zone extends to a very considerable distance below the surface, but its depth is dependent largely upon the original character of the rock, being less in proportion to its original massiveness. This rock, so thoroughly disintegrated that it breaks upon exposure into small fragments, is the material to which the native name *cascajo* is applied. The term is a convenient one with a perfectly definite meaning, and should be used, if at all, with discrimination. It is probable that all the material on the west side which has been classed as soft or disintegrated rock can be excavated with a steam-shovel without blasting. The material stands in natural slopes of 60° or more, and artificial slopes equally steep will probably be entirely safe.

The Machuca formation in its original composition is very similar to the Brito, but it weathers in a very different manner owing to the different climatic conditions on the opposite sides of Lake Nicaragua. The Machuca sandstone is intersected by numerous joint planes, but the consequent disintegration is much less prominent than the rock decay, and this has generally gone so far that the resulting product is more properly classed with the clay than the soft rock. Although some traces of the original rock structure remain within a zone covering

the hard rock, it will for all engineering purposes be treated as clay.

Among the volcanic rocks of the east side the material classed as soft rock is quite different from the cascajo above described. It may be considered under three varieties; first, that derived from basalt; second, from dacite; and, third, from volcanic sandstones and conglomerates.

The basalt is first intersected by joints which break it up into large rhomboidal blocks. From these joints the weathering progresses inward, and successive layers are separated from the core of fresh rock within. These cores remain as boulders, and, as already stated, are found in the zone of residual clay as well as in that of the soft rock. The basalt varies considerably in texture. The upper and lower surfaces of a lava flow are usually more or less vesicular, and the basalts of this region appear to be largely lava flows. These vesicular portions are more readily penetrated by the percolating waters from the surface and their decay is correspondingly more rapid, hence it often happens that the central compact portion of a lava flow will be marked by a nearly continuous layer of fresh boulders, while the vesicular portions above and below will be thoroughly decayed and few if any boulders will remain. The basalt is, when fresh, a hard black rock which rings under the hammer, and is altered to a soft, bluish-gray or rusty yellow material which can be readily cut with a knife, but in which the original structure of the rock is more or less distinctly preserved. This material is not plastic and is more permeable to water than the residual clay.

The dacite is originally a very firm rock which generally weathers from the surface downward rather than from joints toward the center of rhomboidal blocks. The soft rock derived from its decay, therefore, is more uniform in structure than that derived from the basalt. It rarely contains residual boulders of the fresh rock, and preserves much more perfectly the original structure of the rock from which it is derived. It forms a pink or gray material soft enough to be cut with a knife, in which the constituent minerals can be readily distinguished, but in which all minerals except the quartz are thoroughly decayed.

The volcanic sandstones and conglomerates weather somewhat like the dacite. There is a regular downward increase in amount of decay and all parts of the rock weather equally, the fine matrix as well as the large pebbles. The resulting material retains perfectly the original structure of the rock, the pebbles being distinct and in their original shape, but the whole mass so soft that it can be readily cut, and in some cases it might well be classed as clay.

The three classes of materials above described —alluvium, residual clay and soft rock—should be considered as earth in making estimates for excavation. The soft rock, however, may require some blasting, particularly toward the bottom and where it contains very large boulders. It will stand with much steeper slopes than the alluvium and clay and will be less liable to slip. Not being plastic it will also support a heavier load and hence may be relied upon for foundations where the weight of the structure is not excessive. For these reasons it seems desirable to make the distinction between clay and soft rock wherever possible. It should be clearly understood, however, that when considered with reference to cost of excavation the material classed as soft rock must be regarded as earth. It will be somewhat more difficult to handle than the residual clay, chiefly by reason of the greater number of boulders which it con-

tains, but it will probably be handled with considerably less difficulty than glacial drift, boulder till or hardpan.

Hard Rock.—So extensive has been the rock weathering in this region that fresh rock rarely appears at the surface, and in most cases none has been reached at the depths penetrated by the diamond drill. By fresh rock is here meant one in which the constituent minerals have suffered no alteration. The residual boulders of basalt, however, are surprisingly fresh, and even when examined under the microscope it is found that the constituent minerals have been altered scarcely at all. By hard rock is meant, in this connection, therefore, not a rock which is unaltered, but one which is hard enough to require blasting for excavation. In practice the line between hard and soft rock was, in general, placed at the point where the diamond drill began to yield a fairly continuous core. This criterion is open to objection, since a very soft rock will yield a core if it is perfectly homogeneous, while a very hard rock will not core if some portions are harder than others. The hard portions choke in the bit and grind up the softer portions, particularly if the rock is intersected by joints.

As there is a gradual transition from residual clay to soft rock, so there is a similar gradual transition from soft rock to hard rock, and the separation of the two classes of material is, to a certain extent, arbitrary. In some cases the residual boulders become more and more abundant until they pass into a massive rock intersected by few insignificant joint planes. In other cases, as in that of dacite, the rock becomes very gradually harder by reason of the less altered condition of the constituent minerals until it may be regarded as hard rock. It is safe to predict that the surface separating the two will nowhere be found so regular as it is represented on the sections.

The rocks of the region have been rather fully described in a previous part of this report, and but little further remains to be said concerning them. The primary classification as sedimentary and igneous rocks is of considerable importance to the engineer and also the particular manner in which each class of rocks weathers.

The heavy dark-colored basic rocks which are grouped together as *trap* are the hardest rocks which will be encountered on the line of the canal. They are admirably adapted for concrete work but would shatter in blasting and hence probably could not be taken out in blocks of sufficient size for use in a rock fill dam as the Canal Company proposed to build at Ochoa. They would also be poorly adapted for use where dimensional blocks were required on account of the cost of quarrying and dressing.

Next in hardness is the dacite. This is tougher than the trap and probably would not shatter in blasting, so that blocks of any size required might be taken from the cuts. It might also be quarried in dimensional blocks and dressed with comparative ease. Quarrying, however, would be expensive by reason of the great depth of residual and decayed material which everywhere covers the hard rock. Its rapid weathering, noted above, would render it a decidedly inferior building stone. The various sedimentary rocks differ widely in hardness and show considerable variation even in a single formation. In a general way the hardness decreases in the following order—Machuca sandstone, volcanic sandstone (Ochoa), Brito sandstone, basaltic tuff (Eastern Divide). This order applies only to the average hardness, and certain beds could be selected from the several formations which would occupy a different order.

A matter of considerable importance to the engineer is the specific gravity of the rock with which he has to deal, especially that which is used for construction purposes.

The following table gives the specific gravity and weight per cubic foot of the more important varieties of rock on the canal lines. The determinations were made by Mr. George Steiger in the laboratory of the U. S. Geological Survey. The material was allowed to stand in water for several hours before weighing, so that the values given in the table correspond with those which would be found if freshly excavated material were examined. The specific gravities are somewhat lower than would be found for thoroughly air-dried material. The weights per cubic foot, however, exceed those for dried material by the weight of the water which a cubic foot of the dried material would absorb.

The average values given by Trautwine for four varieties of rock are added to the table for comparison.

Name.	Locality.	S. G.	Average S. G.	Wt. per cu. ft.
1. Andesite	Rio Grande, hole 3, 37′	2.75		171
2. Dacite	Eastern Divide, hole 3, 109′	2.26	2.28	141
3. Dacite	Eastern Divide, hole 4, 140′	2.30		143
4. Dacite	Lower Ochoa, hole 3, 33′	2.63		164
5. Olivine free Basalt	Sarapiqui hills, spec. 170	2.77		173
6. Olivine Basalt	San Francisco hills, spec. 163	2.88	2.81	180
7. Olivine Basalt	Upper Ochoa, hole 9, 83′	2.88		180
8. Hypersthene Basalt	San Carlos Hills, spec. 44	2.73		170
9. Sandstone	Machuca creek, spec. 139	2.67	2.67	166
10. Sandstone	Las Lajas, hole 1, 16′	2.67		166

AVERAGES GIVEN BY TRAUTWINE.

Name.	Average S. G.	Wt. per cu. ft.
Basalt	2.9	181
Granite	2.72	170
Limestone	2.7	168
Sandstone	2.41	151

No. 1 Andesite forming the hills north of the Rio Grande valley about 8 miles from Brito, is a compact crystalline rock which will probably be found the best available material for the construction of breakwaters at Brito harbor. Its density is slightly greater than that of the average granite.

Nos. 2 and 3 represent a fair average of the dacite in the Eastern Divide. This is the lightest rock on the canal line, and in that respect is inferior to the traps as material for rock-fill dams, where high specific gravity is of special importance. It is, however, the rock which would be chiefly employed for that purpose if the Menocal route were adopted.

No. 4 is a dacite encountered at Lower Ochoa which is more compact and much darker in color than the dacite of the Eastern Divide. The presence of the dark iron silicates gives it a rather high specific gravity, though it is lower than that of the basalts.

Nos. 5, 6, 7 and 8 represent the dark igneous rocks, varieties of basalt, classed together as trap. Their average specific gravity is slightly under the average given by Trautwine for basalt. These are the rocks which will be chiefly relied upon for structural purposes if the Lull route is selected.

Nos. 9 and 10 represent average samples of the sandstone beds in the Machuca and Brito formations. Their specific gravity is somewhat above the average for sandstone given by Trautwine.

FACTORS DETERMINING RELATIVE COST OF EXCAVATING HARD ROCK.

In considering the cost of excavating the material classed as hard rock on the line of the canal, two elements of cost which need to be considered here as elsewhere are, first, the drilling, and, second, the blasting. These two elements may or may not vary in the same direction in different rocks, since they depend upon different physical properties. The relative ease of drilling depends on the hardness of the constituent minerals, on the character and amount of cements by which they are bound together, and, to some extent, on their density; in other words, on their relative induration. The relative ease of blasting, on the other hand, depends on the cement which binds the particles together, or their cohesion; on the original or secondary planes of weakness in the rock, such as bedding planes, flowage surfaces, fault fractures, shrinkage joints, compression joints, etc.; also on the presence or absence of grain in the rock. It is thus seen that many variables enter into the problem. An idea as to the cost of excavation can best be reached perhaps by arranging the various rocks to be excavated in the Nicaragua Canal, together with other known types, in a scale showing relatively their induration, which may be regarded as determining the cost of drilling, and their toughness, which determines the cost of blasting.

It should be noted that the arrangement is based on the character of the various classes of rocks as they actually occur in this region in a more or less disintegrated and weathered condition. If the rocks were entirely unaltered their relative position in the scale might be quite different from that given.

Relative Induration.		Relative Toughness.
Basaltic tuff.	1	Basaltic tuff.
	2	
	3	
	4	
	5	Brito sandstone.
	6	
	7	
Brito sandstone.	8	Machuca sandstone.
	9	
Limestone of Chicago drainage canal.	10	Limestone of Chicago drainage canal.
	11	
	12	Volcanic sandstone.
Volcanic sandstone.	13	
Machuca sandstone.	14	
Dacite.	15	Basalt.
	16	Dacite.
Basalt.	17	
	18	
	19	
Granite (unaltered).	20	Granite (unaltered).

The basaltic tuff is at the bottom of the scale both in induration and toughness, and there may perhaps be some question as to the propriety of placing it in the class of hard rock.

The Brito sandstone is low in the scale of induration because it is composed largely of soft minerals bound together by a calcareous cement. It is low in the scale of toughness because it is intersected by well marked bedding planes and also, to a greater depth than the excavation will reach, by many joint planes.

The Machuca sandstone is low in the scale of toughness because of its bedding and joint planes, and rather high in induration because of

the considerable proportion of quartz which it contains.

Dacite and basalt are rather high both in the scale of relative induration and relative toughness because of the hardness and cohesion of their constituent minerals and the scarcity of primary or secondary planes of weakness in the rock. Joint planes are somewhat more abundant in the basalt than in the dacite, otherwise the former would be higher in the scale of toughness than the latter.

It will be readily understood that the above table represents conclusions arrived at, not by any exact methods, but by a careful consideration of the physical characteristics of the rocks in question and an attempt to assign to these various characteristics their proper weight as affecting the result. Too much importance should not, therefore, be attached to the conclusions there expressed, and it is quite possible that actual experience may materially alter the relative positions which the various rocks may occupy in the table.

CHARACTER OF DATA ON WHICH GEOLOGIC SECTIONS ARE BASED.

The facts on which are based the conclusions stated in this report and on the various sections furnished to the engineers for use in making estimates are derived from three sources: first, borings made under the direction of the present Commission; second, the examination of surface outcrops and natural sections; and, third, records of borings made by the Canal Company.

Boring Operations.—The outfit employed in the boring operations recently carried on under the direction of the Commission consisted of two parts: the Pierce well-driving outfit, and the diamond drill. By means of the former a two-inch casing was driven down through the unconsolidated residual or alluvial material at the surface into the soft rock and in some cases to the hard rock. The diamond drill was then set up and the section continued to any depth required. During the process of driving the pipe, samples of the material passed through were taken at frequent intervals and a complete suite preserved. All the core obtained by means of the diamond drill has been preserved and arranged in the order in which it was taken. Wherever the rock failed to core, the material brought up by the water was collected and samples preserved. Four hundred drill sections were obtained in this manner, having an aggregate length of 12,337 feet. These sections are distributed as follows: At the La Flor dam site four sections, with a total length of 528 feet; Brito harbor, thirty-nine, with a total length of 1773 feet; on the excavation line near the end of the Rio Grande gorge and at Las Lajas, eleven sections with a total length of 668 feet; at the various dam sites and embankment lines on the east side, 101 sections, with a total length of 4590 feet; in the channel of the San Juan river, 239 sections, with a total length of 4018 feet; and in the Eastern Divide, four sections, with a total length of 759 feet.

Surface Examinations.—The value of the surface examinations varied somewhat widely. In some portions of the region outcrops are so infrequent that little information concerning the character of the rocks could be secured by such an examination and it was therefore devoted chiefly to the physiographic features. Enough residual boulders were usually found in the clay at the surface to determine the character of the underlying rock, although the limits of the various formations could rarely be determined with

accuracy by this means. West of Lake Nicaragua the information to be obtained by surface examination is much greater than in the eastern division. This is chiefly due to the much greater depth of the residual mantle in the latter than in the former region. Also the sea and lake cliffs and the stream channels give tolerably good geological sections which afford much information concerning the character of the underlying rocks.

Records of the Canal Company's Borings.—The records of borings made by the Canal Company are the least satisfactory of the three sources of information. None of this work appears to have been done by men trained in making geological observations. The records are very meager and incomplete. There is no harmony in the terminology employed, and without the specimens it is generally impossible to gain much information from these records. Although many borings were made, in most cases they were not carried to a sufficient depth to furnish the definite information required. In most cases, except on the Eastern Divide, they merely furnish a minimum measure of the unconsolidated surface material. When rock is reported there is always a question whether the rock is not simply a boulder. In a few cases the records appear to be erroneous, perhaps through mistakes in transcribing them. These mistakes, wherever they have been detected, have been uniformly unfavorable to the Canal Company's plans so that they cannot be regarded as intentional. They serve, however, to cast a shade of doubt upon all the records and thus detract materially from any value which they might otherwise have. The most systematic work done by the Canal Company was on the Eastern Divide and the La Flor dam site. The records at these two places, however, would have been quite unintelligible without the additional work done by the Commission.

GEOLOGIC DETAILS.

Western Division.—Beginning with the Pacific terminus the various canal routes will be taken up and the geology of the immediate localities concerned will be described in some detail. This description is given with special reference to the needs of the engineers. Naturally some repetition is involved of matter contained in the first part of this report, but a reiteration of some of the more important geological facts may be made with advantage.

La Flor Dam Site.—Section, Fig. 1, Plate XVII.—The boring done by the Canal Company at the proposed La Flor dam site was more thorough and systematic than at any other point on the line. Only four holes, therefore, were put down by the Commission, and these were for the purpose of verifying the results obtained by the Canal Company and interpreting their records. As a result of this combined work the conditions at La Flor may be regarded as very perfectly known. The old river valley at this point has a depth of fifty feet below sea level, or about ninety feet below the present flood-plain. The section of the valley as developed by the borings is that which would be produced by the continuation of the present slopes with normal curves below the margin of the alluvium. The material forming the sides and bottom of this old valley beneath the alluvium is precisely the same as that exposed in the hills on either side. It is a calcareous shale containing numerous layers of fine sandstone. This material has been somewhat fully described in a previous part of this report. The rock is intersected by numerous joints which break it up into small rhomboidal blocks. In drilling

through such material very little continuous core is obtained since the harder sandy layers tend to choke the bit and grind up the softer portions. The material which comes to the surface with the water then very closely resembles clay. These conditions have led to the designations previously applied to this material, such as "clay and rock in layers;" "rock with clay seams;" "argellite with clay seams;" "layers of stones in clay," etc. Much of the material has been classed as *telpetate* and *cascajo*. *Telpetate* or *tepetate* is a term used in Mexico and other Spanish-American countries for a soft, friable, chalky gray or yellow rock, formed by precipitation from calcareous water, *i. e.* tufa, or from partial solidification of volcanic ash and mud, *i. e.* tuff.

Talpetate is thus described by Levy:[1] "If a cloud of ashes be suspended in the air it is readily seen that the heavier particles are the first to obey the attraction of gravity and that the lighter are the last to reach the surface. Moreover, if the heavier portions are formed of a soft material or are in a state of semi-fusion, it is known that they will become round before they reach the earth. In Nicaragua the name *talpetate* or *talpuja* is given to these layers of ashes. It is a species of fine-grained conglomerate formed of small, smooth and round balls, partially cemented by a finely powdered tuff. In some places the ash does not contain soft material and then it is simply deposited in the order of increasing density; also it is without cohesion and does not contain the small balls."

Nothing which would answer this description occurs at La Flor, and it is clearly a misnomer to apply the term to this more or less disintegrated rock, which is distinctly of sedimentary origin, and contains only a relatively small proportion of volcanic material. *Cascajo*, on the other hand, is properly applied to the surface rock in the vicinity of La Flor. The term is defined by Levy as follows:

"In Nicaragua the name *laja* is given to lava; also the layers of stratified trap are called *lajas*, and, in general, any rock which is distinctly and evenly bedded. When *lajas*, that is bedded rocks of any kind, are disintegrated, forming small easily divisible fragments, this disintegrated material is called *cascajo*."

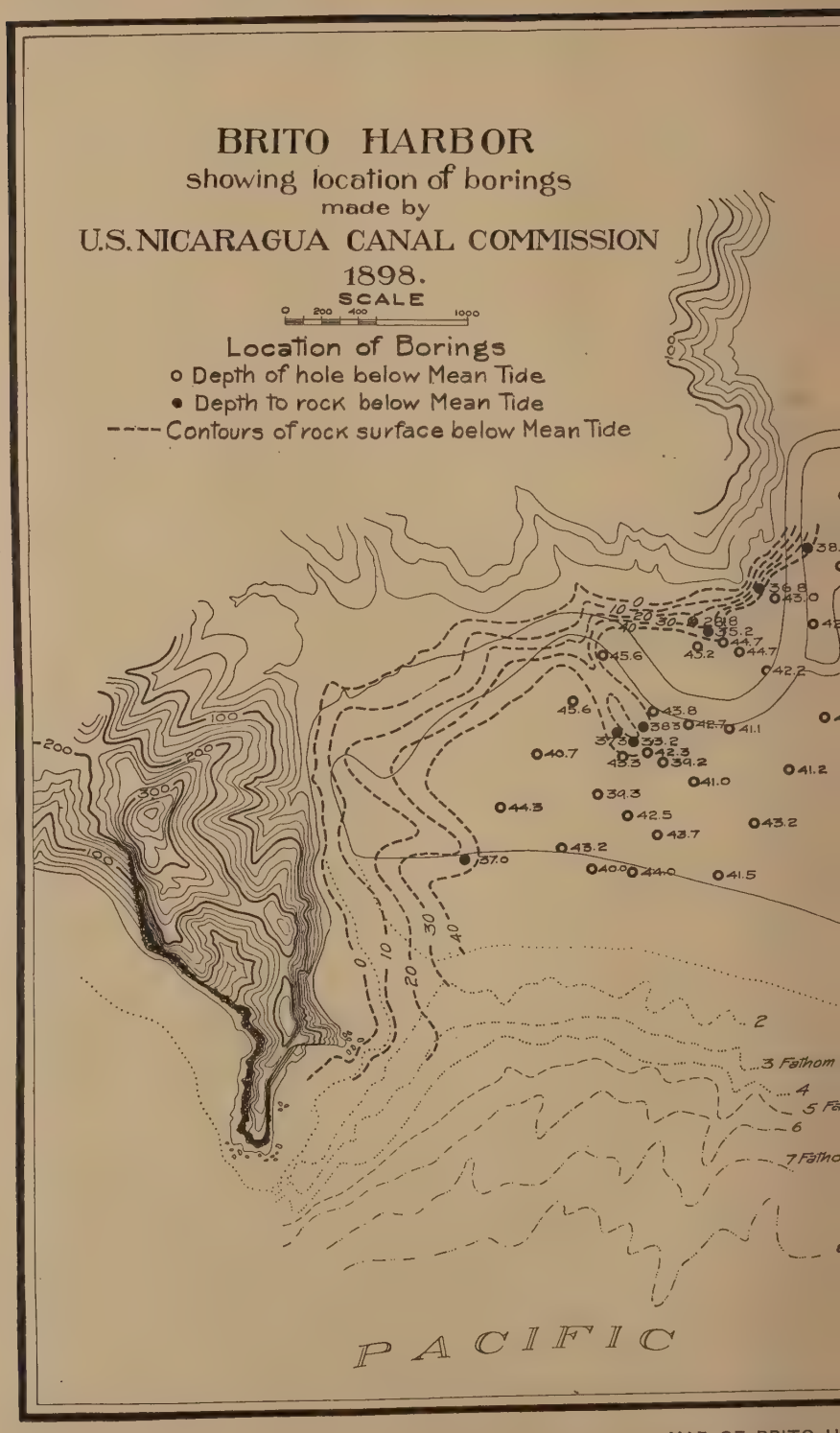
While the rock which forms the bottom and sides of the old river valley at La Flor is more or less disintegrated and breaks up into small blocks when it is removed, it is nevertheless abundantly competent to sustain any pressure to which it would be subjected by a structure such as the proposed La Flor dam. It would, therefore, be necessary in constructing a masonry dam at this point merely to excavate the alluvium down to the bottom of the old channel, fifty feet below sea level. On the sides of the valley above the present alluvium, and perhaps a short distance below it, it would of course be necessary to excavate a few feet of residual sandy clay and thoroughly disintegrated rock in order to secure a satisfactory foundation. In the deeper portions of the valley, however, the transition from alluvium to rock appears to be comparatively sharp and the residual material, if present, is very thin.

Rio Grande Dam Site.—Section, Fig. 2, Plate XVII.—The two Variants I and III of the Childs route between Lake Nicaragua and the Pacific involve the location of a dam and locks at some point in the upper portion of the Rio Grande valley. The site for such a dam having greatest natural advantages appears to be at Buen Retiro, about nine miles from the lake.

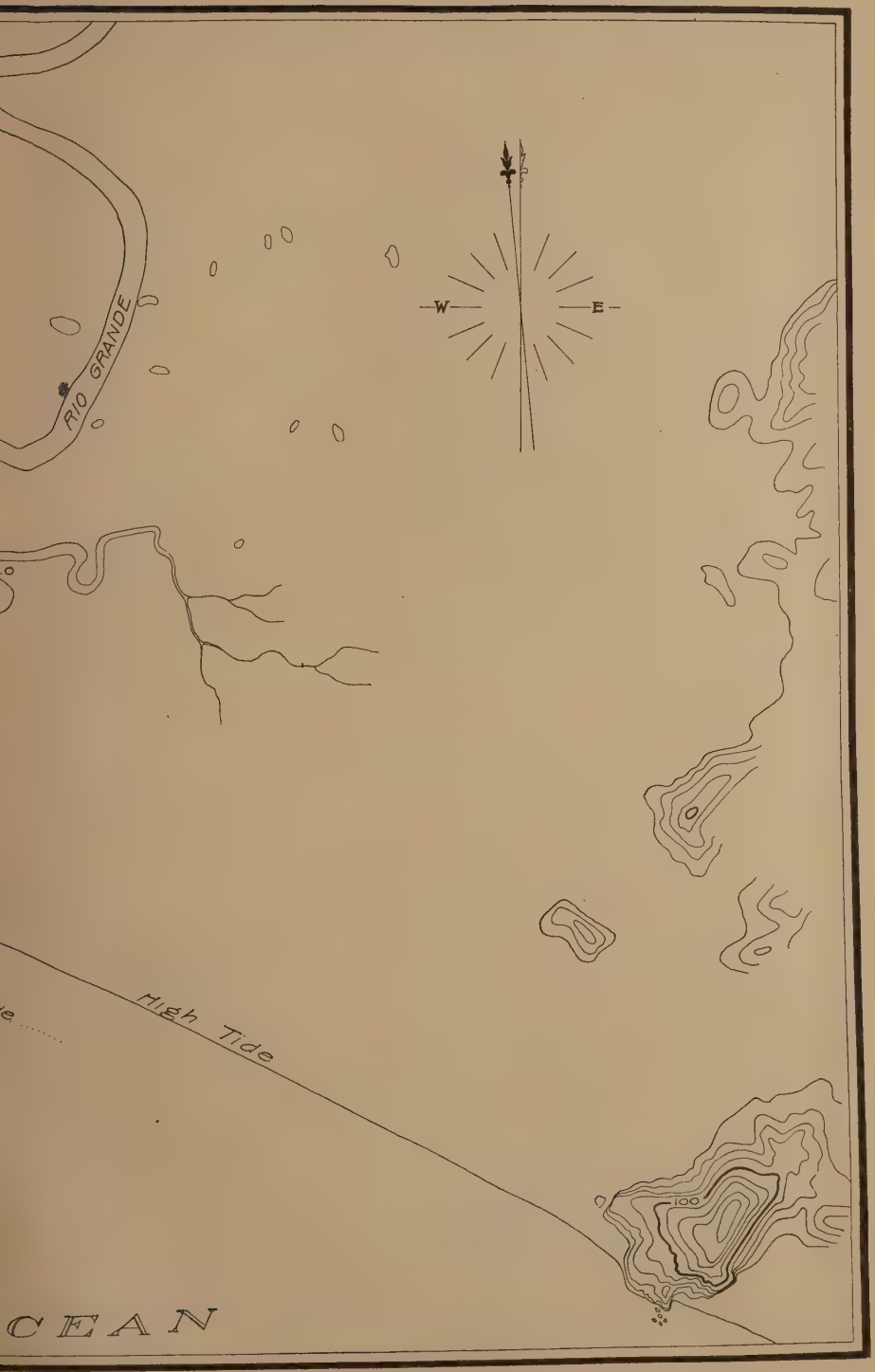
[1] Notas Geographicas y Economicas sobra la Republica de Nicaragua, Pablo Levy, Paris, 1873, p. 145.

The section referred to above shows the geological conditions at this point. The hill which occupies the center of the valley is composed of calcareous shale more or less disintegrated, but sufficiently firm, however, for foundation purposes. The saddle north of this hill was formerly a channel of the river, the rock bottom of which is about fifty feet above sea level. This is considerably below the present bed of the river and is approximately the same depth as the old river channel which is now partially occupied by the Rio Grande. The foundations of the dam at this point would, therefore, be about fifty feet above sea level and comparatively little silt would have to be excavated to place the foundations upon rock. The long gentle slopes of the hills south of the valley are covered by a thin layer of residual clay, under which is more or less disintegrated rock, passing downward at an unknown depth into solid rock. This material would afford suitable foundations for locks or other structures. The material filling the old channel in the saddle is compacted, sandy clay and sand similar to that which partly fills the upper portion of the Rio Grande channel. At some point beneath this silt is the contact of the Brito shale and the underlying andesite. The shale appears to dip away from the andesite as though it had been tilted up by the intrusion of the igneous mass. The andesite forming the hill immediately north of the dam site will afford a convenient supply of excellent rocks for the construction of dams and controlling works at this point.

Brito.—The borings made by the Canal Company on the site of the proposed Brito harbor and shown on the published map which accompanies the report of the Canal Board of 1895, indicate the presence of a rock ledge a short distance below the surface, extending from a point near the beach about 2000 feet, north 30° east, up the valley of the Rio Grande. In order to determine the extent of this ledge thirty-eight holes were drilled, their location being shown on the accompanying map, Plate VII. These holes were put down to depths between forty-five and forty-eight feet below high tide of April 20, 1898. Rock was found in six of these holes but not at the depth or in the positions indicated by the previous drilling. The form of the rock surface developed by these borings is shown by means of contour lines on the map. It will be noticed that the rock occurs only near the northwestern margin of the Rio Grande valley. The prevailing direction of the wind along the beach is such, that the sand is drifted toward the western margin of the valley, and the lower portion of the Rio Grande is constantly crowded over to this side of its valley and for a short distance back from its mouth is cutting the cliff which forms the northwestern headland. By cutting away the base of the cliff the river appears to have formed a narrow shelf on the side of the old valley where the rock is a comparatively short distance below the surface. Portions of the rock have been cut away to a considerable depth, but two ledges formed by harder beds in the sandstone extend out into the valley as shown by the contours. These are similar to the ledge which projects from the extreme outer point of the headland except that their surface is somewhat lower. Southeastward from this rock shelf the old valley extends to the southeastern margin of the Rio Grande flood-plain, and it is probable that no rock would be encountered in this direction to within a short distance of the margin of the valley. Hence a harbor might be located at any point between the headlands with little danger of encountering rock in excavation. The material filling the



MAP OF BRITO H



OWING DEPTH TO ROCK.

old valley consists entirely of sand near the present beach. A short distance back from the beach the sand is overlain by fine alluvial silt which increases in thickness up the valley and forms the banks of the present Rio Grande channel. The greatest thickness of the fine alluvium is perhaps thirty or forty feet at a distance of several miles from the coast. Below this the greater portion of the material filling the old river valley is sand with more or less clay silt.

In the construction of the harbor at Brito a large amount of stone will be required for breakwaters, etc. The character of the rock in the headlands on either side of Brito has already been described. That forming the northwest headland is thin bedded sandstone and shale intersected by many joints. It is, therefore, not suitable for the construction of breakwaters. The limestone forming the southeast headland can be readily quarried in blocks of any desired size and will doubtless be employed until the supply is exhausted. The next most convenient source of supply is in the hills north of the Rio Grande valley at Buen Retiro. The rock here is andesite, a dark, compact, crystalline rock with high specific gravity, 2.75, which can be quarried in any sized blocks required. The residual clay covering the hard rock is comparatively thin, so that quarries can be opened with little dead work.

Excavation Lines, Childs Route, Lake Nicaragua to Pacific Ocean.—Numerous holes were put down by the Canal Company, chiefly with the earth auger, between Las Lajas and the head of the Rio Grande flood-plain. The classification of materials for this portion of the line has been based largely upon the records of these holes, supplemented by one hole put down on the lake shore at Las Lajas and by an examination of the surface conditions in the vicinity of the line. The underlying rock is the Brito formation, which has been already fully described. That part of the formation which reaches the surface from a point a short distance west of the lake to the site of the Rio Grande dam, consists largely of argillaceous shales containing fewer beds of sandstone than the portions of the formation which are exposed on the lake shore and on the Pacific coast. The rock is everywhere deeply disintegrated, and the line between the materials classed as disintegrated rock and as hard rock is difficult to draw, since the passage from one class of materials to the other is generally gradual. In the classification represented on the section the effort has been made to draw this line at the bottom of the material which can probably be excavated without blasting. Within a mile and a half of the lake the line crosses the Rio Lajas four times. This stream appears to be flowing in an old channel which was somewhat deeper than its present channel and which has been silted up. The geological significance of this old channel has been pointed out in an earlier part of this report. It considerably increases the proportion of soft material to be excavated on this part of the canal line. Beyond this old channel the surface is covered with a very uniform layer of residual clay derived from the decay of the underlying shales. Its thickness varies from four to six feet and it passes downward somewhat abruptly into the underlying disintegrated shale or *cascajo*. As indicated by the Canal Company's borings the disintegration of the rock has extended to a somewhat greater depth upon the Divide than elsewhere, and if the conditions are found to be as represented on the section, the hard rock will extend but a few feet above the water level in the canal through the greater portion of the Divide cut. The hard rock is represented as passing below

the bottom line of the canal between six and seven miles from the lake.

The Rio Grande is also found to be flowing in an old channel which has been in part silted up. The present river channel occupies from a third to a half of the old channel. By a careful examination of the present river banks it has been possible to map the old channel with tolerable accuracy. The Canal Company's borings have given its depth and upon this basis the canal profile has been constructed, showing the proportions of earth and disintegrated rock to be excavated. On the Childs route, Variant II, no excavation will be required between the head of the Rio Grande flood-plain and the dam at La Flor. Three sections were made by the Canal Company on the site of the proposed locks in the hills north of the La Flor dam site. The records of these holes would be difficult to interpret but for the work done under the direction of the Commission at La Flor. The surface is covered with a thin mantle of residual clay which passed downward into disintegrated rock. Below the disintegrated layer the rock consists of interbedded sandstones and shales, the latter being rather soft and intersected by many joints. A considerable proportion of the material to be excavated in these hills and in the foundations for the locks should be classed as hard rock, but it is impossible with the present information to make definite statements concerning the proportions of hard and soft rock. Beyond La Flor the excavation will be entirely in alluvial material consisting of clay and sand to the site of Brito harbor.

Only a single route has been considered from the lake to the Cano Guachipilin. From this point westward three alternatives have been considered. These are, the three variants of the Childs route described in the report of the Chief Engineer. Variant III follows the north side of the Rio Grande valley; and, Variant I follows the south side of the valley. The classification of materials on Variant II has already been given. Variant III provides for a dam across the Rio Grande at Buen Retiro, the canal passing through the low saddle north of the hill which here occupies the center of the valley. Ten holes were put down by the Commission on this line within a distance of about two miles from the crest of the Buen Retiro saddle. These holes show that the hill in the center of the valley was formerly an island in the river. There is an old channel to the north of it, extending to a depth of seventy feet below the present surface, the material with which it is filled being compacted sand. Three thousand feet beyond the saddle the line crosses a spur from the hills to the north, the old channel bending to the left and joining the present river channel. Sandstone is found beneath a thin mantle of residual clay on the point of this spur. Beyond this the alluvium of the present Rio Grande flood-plain is encountered, and this extends below the bottom of the canal entirely to Brito. The hills north of Buen Retiro are composed of hard black crystalline rock which is probably a large intrusive mass in the Brito formation.

Variant I follows the southern side of the Rio Grande valley from a point above Buen Retiro to Brito. It also involves a dam at the same point as Variant III. The excavation on the south side of the valley will be chiefly in residual clay and disintegrated rock to a point nearly opposite the mouth of the Rio Tola. From this point to La Flor the excavation will be in the alluvial silt of the Rio Grande flood-plain. At La Flor the point of the hill which forms the southern end of the proposed La Flor

dam is utilized as a site for a lock. The rock here is entirely a disintegrated sandy shale, and probably no solid rock would be encountered. The remainder of the excavation to Brito will be entirely in alluvial silt with the exception of a short distance through a hill on the south side of the valley which has been selected as a lock site. The depth of the residual clay in this hill has been taken at about twelve feet, and it is assumed that below this will be found disintegrated rock extending below the bottom of the lock foundation. This disintegrated rock, however, is abundantly competent to sustain any structure such as a lock which may be placed upon it.

Dam Sites on the Rio San Juan.—Sections showing the geological conditions at the proposed sites of eight dams across the San Juan have been prepared for use by the engineers in making estimates. No boring was done with special reference to three of these sections which are therefore based upon the general series of river holes. Five of the proposed sites were more or less thoroughly investigated with special reference to their use for dams. The sections of these will be found on Plate XVII.

Castillo.—At Castillo the site selected for a dam required by one of the variant plans, is immediately above the rapids. But little boring was required here to determine the character of the material forming the river bed and hence the foundation of the proposed dam. The rapids are formed by solid ledges of basalt included with the group of trap rock already described. At low stages of the river the rock can be readily examined on either side. It is intersected by horizontal joint planes which give it somewhat the appearance of a stratified rock. It is believed that the rock in the bed of the river is firm and solid and will form a suitable foundation for any structure which it may be desired to place on it. In the hills on either side of the river the rock is considerably fractured near the surface and the slopes are covered with talus, but the solid rock is exposed at various points and no difficulty need be apprehended in securing suitable anchorages. Three holes were put down here, two on opposite sides of the rapids, and one below on the south side. The first two penetrated solid rock from the bed of the stream downward, while the one below the rapids revealed a deep hole excavated in the rock in the nature of a large pothole. Some additional topography should be taken on the north side of the river before a suitable site for locks can be selected.

Upper Machuca.—The next site selected as a possible dam site is about three miles above Machuca. No borings were made directly upon this site so that the section rests largely upon inferences from the character of the river bed as revealed by borings short distances above and below. The rock here is calcareous sandstone, belonging to the Machuca formation, which is not usually found weathered to anything like the same depth as the igneous rocks of the region. Solid rock is usually found under a few feet of sand in the river channel, but the rock in the adjacent hills is probably weathered down nearly to the same level as the surface of the solid rock in the channel, so that the anchorages must be in residual clay and soft rock.

Machuca.—Section, Fig. 3, Plate XVII.—The Machuca dam site is located about half a mile below the mouth of the Cano Machuca at the upper end of Campaña island. Six holes were put down on the center line; one on the north bank of the river, one in each channel on opposite sides of the island, and three on the south bank. The Machuca sandstone is exposed

on the north bank of the river. It is a fine-grained, light bluish-gray rock, evenly bedded and closely resembling a fine-grained quartzite. It, however, contains some carbonate of lime as well as some feldspathic minerals and much disseminated pyrite. The beds have a dip of about 12° to the west, that is upstream.

The hole on the north bank penetrated twelve feet of tough red clay and then twenty-six feet of soft yellow and white rock derived from the decay of the Machuca sandstone, and at a depth of thirty-eight feet from the surface encountered a hard sandstone similar to that exposed on the river bank. In the center of the north channel a few inches of sand were found, under which is hard sandstone. The sandstone is also exposed on both sides of Campaña island near its upper end. It here has the same character as on the north bank. At the extreme upper point of the island there are large blocks of igneous rock which appear to be nearly if not quite in place. This rock is a weathered diorite and probably occurs as a dike intersecting the Machuca sandstone. In the center of the south channel there are about seven feet of boulders and sand, then twelve feet of soft rock, below which the hard sandstone is encountered at a depth of thirty-five feet below the water surface. The two holes located on the south bank near the outer and inner edges of the flood-plain, penetrated silt and sand to a depth of about twenty-eight feet from the surface, and then soft rock for a distance of about twenty feet. The hole upon the river bank reaches hard rock at a depth of fifty feet below the surface. The hole on the hillside at the south end of the dam shows forty feet of red and yellow clay and ninety feet of clay and soft rock. The great depth to which the rock is here weathered is somewhat surprising since it does not appear to differ essentially from that found on the north side of the river, where the depth of weathered material is only moderate. It seems probable that the presence of the diorite dike in the sandstone has led to its more rapid decay here than elsewhere. Large blocks of the diorite are found at the head of the island, as stated above, and residual boulders of the same rock are found in the red clay on the hills south of the river. It is quite probable that hard rock will be found much nearer the surface a short distance either up or down the river. The influence of the dike probably does not extend more than a few hundred feet on either side of the center line of the dam. Of the two channels the one on the north side of Campaña island now carries the most water. The south channel, however, was formerly much the larger and this channel has been contracted to half its original dimensions by the deposition of silt. At present the river appears to be cutting only upon the north bank.

Conchuda.—No borings were made with a direct reference to the investigation of a dam site at this point. A few holes were put down in the vicinity, however, which afford a fairly satisfactory measure of the depth of the old river channel and afford some information concerning the character of the rock and the depth of rock decay. The depth of the old river channel is about sixty-five feet below the level of the flood-plain, or four feet above sea level. This old river channel is partially filled with fine clay, silt and sand. The river appears to be cutting its southern bank and has perhaps recently modified the slope of the old valley. The rock in this region is a sandstone containing a very large proportion of volcanic material. In a hole on the point of the hill at the Conchuda cut-off the depth of the residual clay was found to be fifty-four feet. Below this soft rock was

penetrated to some distance, growing gradually harder and probably passing into hard rock at a depth of about sixty-five feet from the surface. It will be readily understood that the information concerning conditions at this point is sufficient only for a preliminary estimate and that further boring would be necessary before final plans could be made if it should be selected as a dam site.

Boca San Carlos.—Section, Fig. 4, Plate XVII.—The dam site at the Boca San Carlos extends from the point of a spur connected with the high hills lying between the San Juan and the San Carlos and a long spur from the lower hills to the north of the San Juan valley. Six holes were put down on the center line of the dam site and one at a little distance from it to the east. Of these one is upon the flank of the hill to the north, three on the flood-plain, one in the river channel near the northern bank and one on the hill to the south of the river. The sections derived from four of these holes are shown on Plate XIII. On the north side of the river above the margin of the flood-plain the red and yellow clay has a depth of about twenty feet. Below this is soft rock containing many residual boulders derived from the decay of basaltic lava. The depth to hard rock, which was reached only in one of three holes, above the flood-plain, and that at a distance of 1000 feet east of the dam line, is probably between fifty and sixty feet from the surface. The holes upon the flood-plain and at the edge of the river channel pass through silt and sand to a maximum depth of fifteen feet below sea level or eighty-two feet below the surface of the flood-plain. This is the greatest depth of the old river channel at this point. The position of the present river is at the extreme southern side of the old channel, and it appears to be cutting this bank to a moderate extent. On the south side of the river the red and yellow clay has a depth of forty feet and the soft rock an equal depth, making the distance from the surface to hard rock eighty feet. Both the residual clay and the soft rock contain many residual boulders of hard rock, and the distinction between the two classes of material is not sharp. The material filling the old river channel is in part black sand and in part fine blue sandy clay silt. The sand is doubtless derived from the San Carlos river, being similar to that found in the river channel from the mouth of the San Carlos to the sea. When the San Juan is low and the San Carlos is in flood, the current in the former is reversed, and the black sand brought down by the latter has been carried some distance up the San Juan. The silt and the sand are not separated by a distinct plane, but are to a certain extent interstratified at their contact.

It is evident that the foundation for a masonry dam will have to be carried down to solid rock, which is found at the bottom of this old channel. At the ends of the dam the foundation should be carried down to hard rock, at least as far into the hills as the end of the crest over which the water is allowed to discharge. Beyond this the soft rock will probably afford a sufficiently solid foundation.

Ochoa.—Section, Fig. 5, Plate XVII.—More systematic work was done under the direction of the Commission at Ochoa than elsewhere, and the information concerning the underground conditions is correspondingly complete. The conditions actually found and inferred were represented for use of the engineers by means of seven sections—three transverse and four longitudinal. One transverse section (C), the one referred to above, Fig. 5, Plate XVII, is approximately upon the center line of the proposed dam

as located by the Canal Company. This section is based on the results obtained in eleven holes and may be regarded as very accurately representing the conditions as they actually exist. Two additional sections are given parallel with the center line of the dam and about two hundred feet on either side. The downstream section (B) is based on two holes on the south side and one on the north side of the river. So far as they were determined the conditions here correspond very nearly with those on the center line. The upstream section (A) is based on the inferred rock slopes represented on the longitudinal sections.

It should be noted that two distinct classifications are represented on this section. One is purely from the engineer's standpoint and consists as elsewhere of alluvial silt, residual clay, soft rock and hard rock. The geological classification has been referred to on a previous page and is quite different. Thus the residual clay and soft rock are derived from three entirely distinct formations, which differed somewhat widely in their original composition and appearance. The hard rock on the south side of the river is composed of two distinct varieties of lava, while that on the north side is composed of a volcanic conglomerate or sandstone. The residual clay as elsewhere is deep red in color for a distance of ten or twelve feet from the surface, below which it is generally blue or gray, and becomes less plastic downward. It merges into soft rock by insensible gradations, so that the line separating the two classes of material is here as elsewhere to a large extent arbitrary. As stated above, the soft rock is derived from three distinct formations, and its character varies somewhat with the original character of the rock. The most compact is that derived from the volcanic sandstone. Next, that derived from the dacite, although the latter is apt to be talcose and hence would not form a reliable foundation material. The soft rock derived from the basalt varies in character with the original character of that rock. Where the latter was compact the material resulting from its weathering is also compact, and where it was vesicular the resulting material is porous.

Lower Ochoa.—Section, Fig. 6, Plate XVII. —Six holes were put down at the proposed dam site at lower Ochoa, two on either bank and two in the river channel. These holes reveal conditions which are very much less favorable for foundations than was anticipated. The rock forming the surface is a volcanic conglomerate or breccia somewhat similar to that underlying the basalt at upper Ochoa. On the south side of the river this is weathered only to a moderate depth of about forty-five feet, while on the north side it is weathered to a much greater depth, in fact, entirely to the bottom of this formation. On the south side it has a depth of about fifty feet, and is underlain by a bed of hard basalt. The upper surface of the basalt, which is doubtless a lava flow, dips rapidly to the north and passes from about thirty-five feet above sea level on the south side to eighty-five below sea level on the north side of the river. As stated above, the volcanic conglomerate and basalt are in contact on the south side of the river, but on the north they are separated by the thin edges of two other formations. These are a bed of soft talcose volcanic rock, probably tuff, about twenty feet thick and a bed of extremely soft sandstone or partially cemented sand which contains numerous fragments of wood, leaves, etc. This latter material is undoubtedly of sedimentary origin, but the constituents are probably derived in large part from a volcanic source.

It is thus seen that in order to secure a solid

foundation on the north side of the river it would be necessary to go down to the surface of the basalt, which is eighty-five or more feet below sea level and at least 135 feet below the surface of the river.

Tambor Grande.—Section, Fig. 7, Plate XVII.—Five holes were put down at the Tambor Grande dam site, two on either bank and one in the river channel. The geological conditions found at this site are more uniform than those observed at any other point. Only a single geological formation was encountered, namely, dacite. This is a rather coarse granular gray crystalline rock which weathers uniformly from the surface downward, the weathered products containing no residual boulders of fresh rock. The surface, as elsewhere, is covered with red clay which passes down into the soft rock by a gradual transition. The soft rock in turn becomes gradually harder downward, and at a depth varying between 100 and 120 feet from the surface the rock becomes sufficiently hard to yield a continuous core with the diamond drill. The surface of the hard rock has a somewhat more gentle slope than the present land surface. The hole in the river channel and the one on the flood-plain north of the river revealed the presence of an old river channel of great depth. The hole on the flood-plain passed through thirty feet of fine silt, then alternate beds of silt and sand, and, at a depth of eighteen feet below sea level, penetrated the soft weathered dacite, and, at forty feet below sea level, hard rock. The hole in the river penetrated black sand to a depth of 108 feet below sea level when the hard dacite was encountered. The black sand throughout the entire distance was very uniform in character, except that a few boulders were found immediately overlying the hard rock in the bottom of the channel. Drawing a line through the points which mark the bottom of the alluvial material and continuing the slope of the southern bank downward until it meets the other line, a symmetrical curve is obtained which probably very nearly represents the outline of the old river channel. The finding of a sand-filled channel at the Tambor Grande site was by no means a surprise, though it was scarcely expected to find it so deep. From the borings which had been made at various points on the river above, it was found that the old river channel had a fairly uniform gradient which was considerably steeper than the gradient of the present river. Thus from Castillo to Ochoa the gradient averages three feet to the mile, while from Ochoa to Tambor Grande it averages 5.8 feet to the mile. The observed irregularities in the gradient are doubtless connected with variations in the hardness of the underlying rock.

Embankment Lines.—*San Carlos.*—Two embankment lines have been examined connecting the hills southeast of the Boca San Carlos with the upper and lower dam sites. The section of the embankment line which reaches the river at upper Ochoa is based upon surface examination and borings made by the Canal Company. The conditions are very similar to those found at the south end of the Ochoa dam site. The rocks of the region are basalts forming a heavy mantle of deep red clay at the surface with soft rock below, both the clay and soft rock containing numerous residual boulders. The depth from the surface down to hard rock is probably from sixty to one hundred feet. The line reaching the river at lower Ochoa is based upon surface examination and seven holes put down under the direction of the Commission. From the river to a point where the line approaches nearest Cano Curano the surface rock is the volcanic

conglomerate shown in the section at lower Ochoa. This is weathered to a great depth, forming a brown sandy clay. The holes were put down below sea level, varying in depth from 80 to 130 feet, but did not reach hard rock except in the hole farthest from the river where the rock is basalt similar to that on the upper line. It was assumed in investigating these embankment lines that the waste-weirs and sluices would be of such a character that firm clay would afford a suitable foundation. If a rock foundation is essential it will be found at a much shorter distance below the surface on the upper than on the lower line. It is thus seen that the upper and lower embankment lines have about the same relative advantages as do the corresponding dam sites.

San Francisco.—See sections, Figs. 1 to 4, Plate XVIII.—On the San Francisco embankment line borings were made by the Commission only on the flood-plains of the streams to determine the depth of their alluvial deposits. Three holes were put down in the Florida lagoon, three in the flood-plain of the San Francisco, and one each at the Nicholson and Chanchos. A study of the physiography of the region had already indicated the existence of an old land surface developed in the region when it stood at a higher altitude than now and subsequently in part concealed by the alluvial deposits of the present streams. These borings determined the character of the alluvial materials and the depth of the former valleys. It was found that the slopes of the present valleys if continued below the covering of alluvium would coincide with the surface of the old valley. The depth of the alluvial filling having been determined at a few points, it was possible to draw contours representing the surface of the old valleys, and thus to show the probable depth of the alluvium at any point. There are two swamps crossed by the embankment line between the Florida lagoon and the Chanchos which have not been investigated with the drill. Since these swamps occupy valleys tributary to the Danta and the Nicholson they could not have been deeper than the trunk valley at the point where they joined the latter. The depth of the alluvium in the trunk valley having been determined, it is therefore certain that the depth in the tributary will be at least no greater. Hence while the section through these swamps is based upon an inference, it is of such a character that it is considered nearly as satisfactory for giving a maximum measure of the silt as an actual examination with the drill. In all of these old valleys residual clay and soft rock are found beneath the alluvium, although they are not so thick as upon the adjacent hills. The rock obtained beneath the alluvium and residual material is only moderately hard, consisting chiefly of talcose volcanic tuff with the thin bed of earthy limestone already described at the San Francisco. The remainder of the section showing the geological conditions and classification of material in other portions of the San Francisco embankment line than those noted above, is based upon a few borings made by the Canal Company or on inferences from borings made by the Commission at various dam sites in the vicinity.

Tamborcito Point.—One of the alternative lines at Tamborcito swings to the south around the point of the hills and avoids the deep cut involved in the other line. It encroaches, however, upon the channel of the river and requires an embankment from the point of the hills to the lower end of Tamborcito island and thence across the northern channel to the north bank. No reliable information is available concerning

the character of the foundation for this embankment. A line, however, has been drawn on the section to indicate the probable limit of the alluvial material. This line is based on the known depth of the old river channel at Tambor Grande and on the slopes of the adjacent hills. The material below is probably hard rock similar to that exposed at water level and in the point of the hills. That above the line is chiefly black sand with sandy silt forming the island and the flood-plains north of the river. It should be clearly understood that this line represents only a fair degree of probability. There can be little doubt, however, that the black sand has a depth of at least eighty feet on the line of the embankment, and it may be considerably greater. Hence it will probably be necessary to design an embankment which can rest upon this sand as a foundation.

Tamborcito Lagoon.—Section, Fig. 5, Plate XVIII.—An essential part of the plan which involves the construction of a dam at Tambor Grande, is an embankment connecting the hills immediately south of the river with the high land in the interior. This necessitates the filling of a few gaps in the crest of the hills between the river and Tamborcito creek. This latter stream meanders through a broad alluvial flat, similar to those which border the San Francisco and Danta creeks. This alluvial flat is a lagoon more or less perfectly silted up and forested. Four holes were put down to determine the depth of the alluvial material. The old residual surface beneath the alluvium is found to be somewhat irregular, as might have been expected from a consideration of the geological history of the region. The greatest depth of the alluvium was found to be eighty-six feet, or forty-six feet below sea level. Since the foundations for an embankment of the height required would have to rest upon material at least as firm as residual clay, the difficulties of constructing such an embankment across the Tamborcito valley would be very considerably greater than across the San Francisco valley. This embankment line, therefore, has about the same degree of availability compared with the San Francisco embankment line as the Tambor Grande dam site has compared with the Ochoa dam site.

Excavation Lines, Eastern Division.—*River Section, Lull Route.*—The information concerning the materials forming the bed of the San Juan is based chiefly upon a series of borings made under the direction of the Commission, extending from a point in Lake Nicaragua one and a quarter miles from its outlet down the river to the Colorado junction. From the lake to the Toro rapids the holes were put down at intervals of 1000 feet with intermediate holes wherever rock was encountered or its presence above the datum suspected. Between the head of the Toro rapids and Castillo the holes were put down at irregular intervals at points determined by the configuration of the banks and the presence of rock outcrops. Five holes were put down at intervals of 1500 feet on the cut-off between Sombrero de Cuero and Santa Cruz. From Santa Cruz to Machuca the holes were at intervals of about half a mile. So far but a single line of holes was put down as nearly as possible to the probable center line of the canal. Below Machuca another plan was adopted. Certain points on the river were selected at intervals of two or three miles and at each a transverse section of the river channel was developed. The principal object here was to determine the depth and form of the old river channel which extends from Machuca to the sea. Additional holes were also put down between the sections

to determine the depth of the old channel and the character of the rock in the river bed.

The results of this work are shown on the profiles of the river section and may be briefly summarized. Between the lake and the Toro rapids the only points at which rock was found in the river channel were in the immediate vicinity of the hills which rise abruptly above the broad alluvial plain. The conclusion reached independently from a study of the surface features of the region were thus verified by the drilling operations, viz.: that the region once had considerably greater relief, but has recently been submerged by the waters of the lake, and the lower portions of the land surface concealed by the alluvium which has filled their irregularities. While the work is not sufficiently extended to develop this old topography to any considerable extent, it has shown that the slopes of the old land surface beneath the cover of alluvium are essentially continuous with the slopes of the hills which rise above the low-level plain. This conclusion has very greatly supplemented the information obtained by drilling and has afforded a basis for the construction of numerous sections, both longitudinal and transverse to the river channel at all points where rock was found. These sections have been used to determine the distance that the canal line should be shifted away from the hills in order to reduce the amount of rock excavation to a minimum or avoid it entirely. Since it is probable that the canal line can be so located between the lake and the Toro rapids as to avoid all rock excavation, the character of the rock found at various points in the channel of the river is not of great importance. It may be stated, however, that these rocks all belong to the class of traps already described. While a consideration of the physiography of the region as well as the results of the boring in the Toro rapids indicates the presence of an old channel below the bottom of the canal, but subsequently filled with alluvial material, it is probable that this channel cannot be followed by the canal and consequently some rock excavation will be required. The principal part of this will probably be on the point opposite the mouth of the Rio Sabalos. The rock here is a rather soft red rock, probably an altered vesicular lava, although it may possibly be a consolidated tuff. No samples sufficiently fresh for exact determination were obtained. But little excavation will be required below the Toro rapids, except on the cut-off between Sombrero de Cuero and Santa Cruz. Five holes were put down approximately on the canal line between these points. No rock was encountered, the material being in part alluvial and in part residual. The alluvial material was chiefly very fine blue clay, some portions of which contained a large proportion of vegetable matter. The residual clay was red and mottled and in places somewhat sandy, containing some of the original minerals but partially decomposed. A little hard rock will be found above the datum 75 between Santa Cruz and Castillo. This belongs to the class of trap already described. Below Castillo the river bed is nearly everywhere below the datum 75 and no excavation will be required, except a small amount of sand, until the Balas rapids are reached, where the rock rises about eight feet above the datum for a short distance. The rock here is the Machuca sandstone which will probably be found more or less disintegrated to a depth somewhat greater than the excavation. Throughout the whole extent of the Machuca rapids rock occurs in the bed of the river. It is seldom covered by more than a few feet of sand and boulders. Hence, if a lock is located at the upper Machuca dam

site considerable rock excavation will be required between that point and Machuca. This excavation will be in the Machuca sandstone, and, as shown in the section of the dam site at Machuca, the extent to which it is weathered is somewhat variable. The depth of residual clay represented on the section is more probably a minimum than an average measure, and the amount of excavation in hard rock may be considerably less than the estimates which have been made. The character of the rock at the Machuca dam site has already been described. Beyond this point, through the Aguas Muertas, no excavation will be required, except in cut-offs, even if a drop is made both at the upper and lower Machuca dam sites. In the cut-off at Conchuda the greater part of the excavation will be in residual clay and soft rock. A core of hard rock in the highest ridge crossed probably extends to an elevation of seventy feet above tide, or twenty-five feet above the bottom of the canal on the plan which provides for two locks above this point. If the summit level is continued eastward to the Boca San Carlos it is probable that no hard rock will be encountered in the Conchuda cut-off.

Menocal Route.—The section of the high-level canal line from Ochoa to Greytown is based entirely upon borings made by the Canal Company, with the exception of four on the Eastern Divide. These were put down to an elevation of sixty feet above sea level, or fifteen feet below the proposed excavation line. From the information afforded by these four sections in the Eastern Divide a part of the data obtained by the Canal Company has been rendered intelligible. Fourteen holes were put down in the divide by the Canal Company, most of them extending to an elevation of seventy-five feet above sea level, but the terms employed in describing the material encountered are so vague and often meaningless that they have very little value in classifying material.

The comparatively simple geological conditions which prevail in the Eastern Divide are shown on the section, Fig. 6, Plate XVIII. The rocks forming these hills are entirely igneous in origin. They include three distinct varieties. Since they all weather at the surface to a red clay, the discrimination of these varieties and the determination of their underground relations would be impossible except for the information afforded by the drill. The rock forming the surface on the western side of the divide consists of basaltic or andesitic tuff. On the Canal Company's sections this is called "*telpetate*," "concrete," "conglomerate" and "slate." It is a dark greenish brown in color, generally fine-grained, but occasionally showing fragments of basalt or andesite and is generally soft and talcose. On exposure to the air it loses water, and crumbles. The surface of this basaltic tuff dips eastward at an angle of five degrees. It is overlain by a lava flow of dacite about 240 feet in thickness, which also dips eastward at a low angle. The dacite also has a variety of designations on the Canal Company's sections. It is called "concrete," "conglomerate," "trap," "talc" and "dacite." It is deeply weathered, but becomes gradually harder downward and at depths of 50 to 175 feet below the surface it is a comparatively fresh, hard rock. Although the dacite does not crumble when exposed to the action of the atmosphere, as the tuff, it weathers quite rapidly. Cores which were taken out by the Canal Company and left on the surface showed, after an exposure of seven years, a zone of weathering which had penetrated to a depth of one-tenth of an inch. This rate of alteration is very much more rapid than would be permis-

sible in any building stone. The surface of the dacite dips eastward at an angle of about 5 degrees, and it is overlain by basaltic and andesitic lavas which extend eastward to the margin of the San Juan delta. These lavas in the Canal Company's sections are termed "*telpetate*," "trap," "talc," "concrete" and "andesite." They weather in an irregular manner, unlike the dacite. Many residual boulders of fresh rock occur in the red clay at the surface, but the depth to continuous hard rock is perhaps greater than in areas underlain by the dacite.

As shown on the section of the Eastern Divide the sides of the western third of the cut would be wholly or in part composed of the basaltic tuff. This material, as explained above (p. 126), when exposed to the air crumbles rapidly, and it would therefore constitute a source of considerable danger to the permanence of the walls. It might be sufficiently firm when first exposed to sustain the pressure to which it would be subjected but would probably disintegrate so rapidly on exposure as to undermine the dacite and produce slides.

An attempt has been made to estimate the proportion of material which would be excavated from the Eastern Divide cut suitable for dams or other structures. It appears probable that the material which would be taken out in blocks of sufficient size and which would resist disintegration, is confined wholly to the bed of dacite. The tuff underlying the dacite can be removed from consideration at the outset. Even if it could be taken out in blocks of sufficient size, which is extremely doubtful, it would rapidly disintegrate when exposed to the action of the atmosphere, and it would thus introduce an element of weakness into any structure to which it was applied. Practically the same may be said of the basaltic and andesitic lavas overlying the dacite. While some durable material might be derived from the residual boulders in the clay and soft rock, it is not probable that any considerable body of solid rock would be found on the line of excavation above the elevation of 75 A. T. In the dacite itself the material classed as soft rock would of course be excluded, but in addition to this a large amount of material classed as hard rock from the standpoint of excavation and of permanent slopes, would also be excluded from the material suitable for construction purposes. This material is what is known to quarrymen as "dead rock." It gives a dull sound under the hammer, and when examined with the microscope its minerals are found to have undergone extensive alteration. It is usually intersected by incipient fractures which quickly develop when it is exposed to the atmosphere and relieved from pressure. It would be necessary to rigidly exclude all such material from all important structures. When these various classes of objectionable material are excluded there remains about 46 per cent. of the material classed as hard rock or 24 per cent. of the total material to be moved, which would be suitable for use in large and permanent structures.

The borings made by the Canal Company on the Menocal route at other points than the Eastern Divide do not in any case penetrate the hard rock. They therefore afford merely a minimum measure of the residual mantle of clay and soft rock which covers the surface of the country. It is probable, however, that little, if any, hard rock would be encountered on the line of the canal, except at the Eastern Divide. The surface of the hard rock may extend above the bottom line of the canal in the divide between the Machado and the Danta and also between the San Francisco and the Nicholson. There are

no exact data, however, for these portions of the line, and the classification of materials represented upon the sections is derived chiefly by inference from other localities where the original composition of the rocks and the conditions of rock weathering appear to have been similar. The uncertainty connected with estimates based upon such inferences should, however, be fully recognized.

Variants of the Lull Route.—The several variants of the Lull route are so nearly on the same line that they may be considered together from the point at which the line leaves the channel of the San Juan at Boca San Carlos to the head of the delta. Beyond this point the three main variants diverge so widely that they require separate consideration.

After leaving the narrow alluvial flat bordering the river above the Boca San Carlos dam site the line crosses a spur from the high hills to the northward, the highest point passed as indicated by the profile being 160 feet above sea level. No borings have been made directly on this line, but one made at the point of the ridge near the river and the series made on the line of the Boca San Carlos dam site indicate the depth of the residual clay and soft rock at this point. Following the rule elsewhere observed, the thicknesses of the two zones are represented as increasing slightly on the higher parts of the ridge. The section, however, must be regarded as merely tentative and subject to very material modification on more thorough examination. It represents merely a tolerable degree of probability. After passing this first ridge the excavation will be in silt and residual clay until the point of the hill is reached at the mouth of the San Carlos. Here it is probable that some soft rock will be encountered, but no hard rock. Crossing a broad, alluvial plain formed in a tributary valley where only silt will be encountered, the line cuts the points of the ridge west of the Machado. While no borings have been made in this ridge, the rocks are very similar to those encountered at the Ochoa dam site, and it is assumed that the residual material and the soft rock have an equal depth. If this is the case no hard rock will be encountered in cutting these points. It is certain, however, that numerous boulders will be encountered in the residual clay, and these will become more abundant in the soft rock, possibly forming more or less continuous layers. Excavation across the Machado valley will of course be entirely in silt. The high point just east of the Machado forms the northern terminus of the proposed Ochoa dam, and the materials of which it is composed have therefore been thoroughly investigated. Above an elevation of forty-five feet above tide the rock was originally basalt and below this consisted of volcanic conglomerate. The latter weathers more rapidly than the former so that while a few feet at the base of the basalt are fresh and hard, this is underlain by twenty-five feet of soft rock, and the hard basalt may be regarded simply as a large boulder. Beyond Ochoa the excavation will be across alternating low, alluvial flats and the points of steep ridges which extend down to the river. The former contain only silt and the latter chiefly residual clay with probably a few points of soft rock rising above the bottom of the canal. Leaving the main valley and following up the valley of Embankment creek only residual clay and a small amount of silt will be encountered, until the divide is reached between Embankment creek and the drainage of the Danta. Borings at frequent intervals have been made through this divide by the Canal Company. While none of them penetrate the rock they afford a minimum measure

of the depth of the residual material, but probably in most cases do not pass entirely through it. The basalt which forms the surface rock at Ochoa disappears at some point to the west of this divide, and the underlying volcanic conglomerate comes to the surface. As shown by the borings at Ochoa, this conglomerate weathers more rapidly than the basalt, and the depth of the residual material, as shown by the Canal Company's borings and by those made at lower Ochoa through similar material, is considerably greater than where basalt forms the surface rock. It is probable, therefore, that only residual clay and soft rock will be encountered in this divide until the point selected for the lock is reached, while the lock foundations will probably be, in part at least, upon hard rock. Beyond the lock the line follows a tributary of the Danta, and finally the Danta itself, and the excavation will be entirely in clay silt and residual clay. The alluvium encountered in the upper portion of the Danta valley will be found much softer than that forming the flood-plain of the river. Lower slopes will have to be provided for, and probably in some cases, as in the Florida lagoon, special precautions will be necessary to prevent the material from flowing back into the excavated channel. The hills crossed between the Danta and San Francisco rivers are simply the protruding points of much higher hills which have been nearly submerged by the alluvium. They are composed at the surface of residual clay which probably extends below the level of the surrounding flood-plains. The silt forming the San Francisco valley is similar to that of the Danta, but will be found considerably firmer. In the San Francisco hills, the points of which are cut by the canal line, basalt again forms the surface rock. The records of six holes drilled by the Canal Company on the line near the one given in the section have been utilized. As elsewhere they give only a minimum measure of the residual clay. They may in some cases extend a short distance into the soft rock, but there is nothing in the record to indicate it. The section is drawn, therefore, largely by inference from the depth to which the rock decay has been found extending elsewhere under similar conditions. Numerous boulders will be encountered almost from the surface, and these will increase in size and abundance downward until they merge with the solid rock. It is not probable, however, that any considerable body of solid rock will be encountered in cutting the points of these hills. From the San Francisco to the Tambor Grande hills the line crosses a level alluvial plain, while the surface of the residual clay passes entirely below excavation. Since the line is near the river the silt will doubtless be found much firmer than that encountered in the San Francisco valley. At some points between the San Francisco and Tambor Grande hills the basalt disappears, and the latter are composed entirely of dacite which extends at least 120 feet below sea level, and possibly much farther.

As already indicated, this rock weathers in a manner quite different from basalt. The decay proceeds downward from the surface, and no sharply defined residual boulders remain either in the clay or the underlying soft rock. There is a gradual transition from the surface downward, and the division between the different classes of material is to a large extent arbitrary. As elsewhere, however, the rock is considered hard only when it will give a practically continuous core with the diamond drill. As shown on the section on which estimates have been based, the upper zone of residual clay is thinner and the intermediate zone of soft rock is thicker than in

basalt. While the borings from which these thicknesses were taken were on the point of the ridge at the Tambor Grande dam site, at some distance from the line, the classification given in the section may be accepted with a fair degree of confidence.

At some point between the Tambor Grande and Tamborcito hills occurs another change in the rocks, and the dacite of Tambor Grande gives place to basalt in the Tamborcito hills. At the water's edge in the point of the hills there is exposed a coarse volcanic breccia. The constituents vary in size from the smallest fragments up to angular blocks two or three feet in diameter. The matrix is finely comminuted rock and volcanic ash and is only slightly softer than the enclosed fragments. The rock as exposed at the water's edge appears to be almost perfectly fresh. This breccia does not extend far above the level of the river, for at numerous points on the sides and top of the ridge are exposures of weathered basalt with numerous fresh boulders. Two alternative lines have been located across the point of these hills. Line A curves to the south, crossing a bend in the river, the center line nearly touching the point of Tamborcito island. Line B cuts directly across the ridge, the highest point on the center line being 360 feet above sea level. No borings have been made directly upon either of these lines, but a few were made by the Canal Company on the point of the ridge between the two lines. They did not penetrate the rock, however, and afford little information concerning the character of material which would be encountered in excavation. The classification of materials as represented on the sections is taken chiefly by inference from the conditions found at Ochoa, where the character of the rocks is somewhat similar. The classification must, therefore, be taken with considerable allowance, and the relative proportions of the three classes of material may be found quite different from that represented. The section represents, however, the best information available at the present time. On line A the hard rock is represented as reaching a few feet above the flowage line of the canal, involving an excavation of about thirty-two feet in this material. Above this is represented a maximum thickness of forty feet of soft rock and forty feet of residual clay. As elsewhere the slopes of the upper surface of soft rock and hard rock each become successively flatter than the preceding. On the alternate line B which crosses the ridge near its highest point the residual clay is represented with a thickness of seventy-three feet. This may be an extreme thickness, but has been observed under similar conditions elsewhere. The soft rock is represented with the same thickness as on the other line. The hard rock is shown reaching to an elevation of 260 feet. The excavation of this line would thus involve a cut of 230 feet in hard rock, and the character of the rock is such that the excavation would be expensive.

From Tamborcito to Sarapiqui the line crosses a broad alluvial plain in which the surface of the residual material probably passes far below the excavation line.

The proposed location across the Sarapiqui hills follows the location made by the Canal Company. Fourteen holes were put down by the Canal Company on the line across these hills. The work was done, however, with an earth auger and does not in any case penetrate the rock. Rock is in places reported, but there is no indication that it was not a boulder, and it is probable that the surface of the hard rock was nowhere reached. The information afforded by these borings has been utilized in drawing the

sections, but they are at best very unsatisfactory, and an inference from the conditions found elsewhere is in general considered more reliable. The hills are composed entirely of basalt as determined by numerous residual boulders. Where the point of the hills is cut by the river opposite the mouth of the Sarapiqui, the boulders are very abundant and some of the outcrops may represent bedrock in place. Considerable hard rock will be encountered in this cut, and the proportion of hard rock may possibly be somewhat larger than is represented in the section, although the latter is considered a liberal estimate. Unless the alternate line B located across the Tamborcito hills is selected, this is the first point upon the low-level line where any considerable volume of rock would be excavated suitable for constructing dams or for making concrete. As elsewhere in regions underlain by basalt, residual boulders will be found in increasing abundance from the surface downward to hard rock.

After leaving the Sarapiqui hills the line remains in the San Juan flood-plain where the excavation will be entirely in silt until the hills north of Buena Vista are reached, where a lock is located. A number of borings were made by the Canal Company in this region, but they give, as elsewhere, only a minimum measure of the residual clay and afford no information concerning the maximum depth of either clay or soft rock. The rock of the region is entirely basalt, and the classification of materials given on the section is derived chiefly by inference from other regions where conditions are similar. It is probable that no hard rock will be encountered either in the canal excavation or in excavation for the lock foundations. The latter, however, will be upon soft rock which will doubtless be sufficiently solid for the purpose. After leaving the site of lock No. 3 the line crosses a few low hills in which residual clay only will be encountered, and then passes to the alluvial plain of the Rio Negro. Here the excavation will be chiefly in silt, with some residual clay, and possibly also soft rock where the spurs from the adjoining hills project into the valley. In the lower portion of the valley of the Rio Negro the excavation will be chiefly in residual clay with possibly a small amount of soft rock. Across the flood-plain of the San Juanillo the material will be silt until the hill is reached which forms the divide between the San Juanillo and the Misterioso. From this point to the next lock site the excavation will be partly in residual clay, but probably no hard rock will be encountered. This lock (No. 2) has not been actually located on the ground and the topography from which the profile was taken is largely hypothetical. The classification of the materials partakes of the same uncertainty as the topography. No boring has been done nearer this locality than at a point five miles distant, and the character of the rock is not accurately known. It is presumed, however, to be basalt such as is exposed at various points along the San Juanillo and in the hills about Lake Silico a few miles to the south. The geological conditions represented on the section at the site of lock No. 2 are taken by inference from those observed under similar conditions elsewhere. The residual clay is represented with a maximum depth of thirty feet at the top of the ridge and the soft rock with a depth of thirty-five feet. The hard rock is represented as reaching above the center of the lock excavation, so that if the conditions are as represented the lock will rest upon a foundation of solid rock throughout its entire extent. It must be clearly understood, however, that the section represents only a fair

degree of probability and that conditions may be found entirely different from those which have been assumed.

Beyond these hills the line enters the alluvial plain through which the Misterioso meanders, passing a succession of lagoons and deep swamps. The surface material here will be very soft mud which is replaced at moderate depths by rather compact sandy clay silt. The last lock (No. 1) is located on a low hill which rises above the alluvial plain of the Misterioso. The information available with regard to the topography and geology of this site is similar to that of lock No. 2. The topography is only approximate, and no examination has been made of the geology by boring or otherwise. The conditions represented on the section, therefore, must be taken with considerable allowance. It is quite possible that both the residual clay and the soft rock will be found much deeper than represented, so that no hard rock may be found at the depth to which excavation for the lock foundations will go.

The second variant of the Lull route passes through Lake Silico while the third passes to the south of the lake. The statements made in the above paragraph concerning the geology of Variant I to the north of the Silico hills and east of the San Juanillo apply equally well to the Variants II and III except that they should be supplemented with regard to one point. This is the region immediately adjacent to Lake Silico. Although no boring was done in this vicinity opportunity was afforded for examining the geological conditions by the cuts on the railroad now in process of construction. The same deep rock weathering observed at other points was found here, and the conditions are essentially the same as elsewhere except that at one point beds of clay and sand with fragments of plants were found apparently underlying a lava flow. These beds are somewhat distinctly stratified and appear to have been deposited in quiet water, possibly a lake basin. They are entirely unconsolidated and so far as could be observed were not materially affected by the lava flow which has covered them. In the railroad cut the clay beds show a decided tendency to slip. If these beds continue to the southeastward near the level at which they are exposed at the edge of the lake, their upper surface will be considerably above the bottom of the canal. If they are found in this position it is probable that they will occasion considerable trouble in excavating and maintaining the canal. They will tend to slip out from beneath the lava and by sapping it permit the overlying rock to fall down.

The profile indicates that a lock is planned at this point. If the beds of clay have any considerable thickness, as is altogether probable, they would afford an insecure foundation for a lock. On the profile these beds have not been represented on account of the lack of exact information concerning them, but conditions have been represented as they would probably be found if the lava forming the surface continued indefinitely downward. The presence of the beds, however, and the probability that they extend some distance to the southwestward should be taken into account in deciding upon the relative merits of alternative routes in this region.

Practically the same geological conditions will be met on the Variants I, II and III, across the alluvial delta plain between the last residual hills and the coast. As already stated the inner portion of this delta plain is covered by a layer of fine clay silt or swamp mud overlying sand or sandy clay. The layer of mud thins out toward the coast, and the outer margin of the delta plain is composed entirely of sand. The lagoons which are crossed by these lines in the delta

plain have already been described. They contain occasional small bodies of open water, but are generally in a somewhat advanced stage in the process of silting up and where the larger trees have not yet secured a footing are occupied by coarse grass and Silico palms. Low slopes will be required through the more open of these lagoons, and all the alluvium excavated will probably be sufficiently firm to stand in banks with steep slopes when it has an opportunity to become thoroughly drained. With the construction of the canal the water surface in the lagoons will be materially and permanently lowered so that much of the surface now covered with water will be comparatively dry and firm. The extent of this drainage will of course be in proportion to the porosity of the silt which in turn depends on the proportion of sand which it contains. The change which will follow the excavation may be seen in the vicinity of the short section of canal dredged by the Canal Company. The land at some distance on either side of the ditch is perceptibly firmer than elsewhere in the same region.

The behavior of the sand which forms the outer margin of the delta plain when deposited in banks alongside an excavation is seen where dredging has been done at Greytown. The sand is so porous that water falling upon it is at once absorbed and consequently does not gully the steepest slopes.

ADDITIONAL GEOLOGIC WORK REQUIRED FOR FINAL LOCATION.

The geological work done under the direction of the U. S. Nicaragua Canal Commission is sufficient for the preliminary location and preliminary estimates of cost. Before the final location can be made considerable additional information should be secured. This required information will be obtained chiefly by means of drills, although some additional general geological work might well be carried on with advantage. This is generally true of the work which it has been proposed to do at greater or less distance from the line of the canal for the purpose of obtaining information which will be of use for the selection of the best materials to be used in construction and for protecting the works when completed.

The work with earth auger and diamond drill may be divided into two general classes; first, that needed for the classification of materials on excavation lines, and, second, that needed for the determination of the character of foundations for structures such as locks, dams and weirs. Less of the former class of work will be required than of the latter.

On Excavation Lines.—More or less work should be done at the following named localities: At Brito, while it is probable that if the harbor be located toward the south side of the Rio Grande valley no rock will be encountered, still there is no certainty of this, and a sufficient number of test borings should be made to determine this point definitely. If these borings are carried to a considerable depth below the proposed bottom of the harbor the number required will be fewer than if they are carried down barely to the depth of the proposed excavation.

Borings should be continued along the line of the canal on the west side at intervals not greater than a thousand feet, and wherever the line approaches the edge of the valley they should be put down at intervals of three to five hundred feet. This work should be continued entirely to the lake for the purpose of making an accurate classification of the material to determine the methods of excavation, and the slope

at which the material will stand and hence the amount of excavation, these two elements chiefly determining the cost.

Coming to the east side of the lake additional work should be done on the river from the lake to the point where the canal leaves the river channel. Between the lake and the Toro rapids a series of transverse sections should be determined by means of the drill in order to determine more definitely the slope of the rock surface which the work already done has discovered. This will be necessary before the most advantageous location of the canal line can be made. Special attention should be paid to the Toro rapids and sufficient work done at this point to locate the old river channel through this obstruction if such a channel exists. Between the Toro rapids and the Boca San Carlos little work will be required except on proposed cut-offs. The extent of the work will be determined somewhat by the plan which is adopted and the consequent grade of the canal between Machuca and the San Carlos.

Assuming that the low-level line is decided upon, which leaves the river channel at the Boca San Carlos, boring should be done at a number of localities between this point and Greytown. The greater part of the work would naturally be where the excavation was heaviest; that is, where the line crosses the points of hills which extend down to the San Juan river. The object of this work would be, as on the west side, to determine the character of the materials, and hence the methods which can be employed in excavation, and the slopes of the excavation. A further purpose which would be served by careful and systematic boring on these points would be to determine the availability of the material which will be excavated for structural purposes on other parts of the line. If the rock is not of such a character as to form suitable material for concrete and rip-rap it will be necessary to search for such material elsewhere. Systematic boring should be done wherever the canal line crosses alluvial plains at such an elevation that a considerable embankment will be required, in order to determine the character of the silt and whether or not it will form a water-tight embankment without a clay core.

On Foundations.—No work has been done on the west side except at La Flor, with the distinct object of determining the character of foundations for locks and dams. If a low-level route is adopted on the west side systematic examination should be made of the character of the foundations at the various points where locks will be located. The information at hand concerning this region is ample for preliminary location and plans, but considerable additional information should be obtained before the final plans are adopted. The drilling operations will probably show that in some cases the location of the lock sites can be shifted with advantage, since it is not probable that the site selected purely on account of topographic considerations will in every case afford the best foundation. The point selected for a dam and controlling works in the upper portion of the Rio Grande valley should be systematically examined, and the sections which have been based chiefly upon surface examinations should be carefully verified by drilling.

Sufficient work has been done on the various possible dam sites on the San Juan river to afford a basis for preliminary location and to determine the relative merits of the various schemes which involve construction of dams at one or more of these localities. When the plan which appears most favorable has been selected, the dam sites which it involves should be exam-

ined with great thoroughness before the final plans are adopted. Even at the Ochoa site where the most thorough work has been done, considerable additional work would be required. Most of the boring done was confined to a single line, approximately the center line of the dam, but it is evident that the entire area which would be covered by the foundation of the dam should be thoroughly examined. At the other sites this additional work is even more important. No boring has been done on the east side at any locality which will probably be finally selected for the lock sites. The sections which have been submitted showing the geological conditions at the various suggested lock sites are chiefly derived by inference from other localities where examination has been made. While this inference is perhaps sufficient for preliminary location, its weakness has been pointed out in the foregoing report, and no final location or final plans should be made until a thorough examination has been made by means of the drill of the exact conditions below the surface.

PART III

MICROSCOPIC PETROGRAPHY OF THE ROCKS FROM THE NICARAGUA CANAL REGION

By F. LESLIE RANSOME
Asst. Geologist, U. S. Geological Survey

The following notes make no pretense of being exhaustive. They merely record observations made on the hand-specimens and their sections, unconfirmed by chemical examination. The feldspars have been determined by the methods of Michel Levy, Fouqué, and Becke. It is evident that some of the volcanic rocks described are close to the line between augite-andesites and olivine-free plagioclase basalts. In such cases chemical examination might result in placing with the basalts one or more of the andesites of the following table, or vice versa. Although in many cases collected from residual boulders in clay, the massive volcanic rocks are usually strikingly fresh, showing that the active transformation, from rock to soil or clay, is often confined to a very narrow zone. The passage from clay to fresh rock would seem to be remarkably sharp as compared with the weathering which takes place in temperate regions.

In their general character, the volcanic rocks resemble those described by Hague and Iddings [1] from San Salvador. The rocks of both regions range from acid to basic varieties. The basalts and andesites are frequently hypersthene-bearing, and dacites occur which possess both andesitic and rhyolitic features.

March 18, 1899.

[1] Notes on the volcanic rocks of the Republic of Salvador. Am. Jour. Sci., Vol. XXXII, 1886, pp. 26-30.

Number of Specimen.	Name.	Locality.	Description.
7–a	Hypersthene-basalt.	San Carlos embankment Line, 2½ miles S. of Upper Ochoa dam site. Residual boulders in red clay.	Megascopically: Dark, nearly aphanitic, of basaltic aspect. Weathers superficially to a yellow ocherous crust. Microscopically: Porphyritic structure, with nearly holocrystalline fluidal groundmass. Essential constituents are basic plagioclase (labradorite or anorthite) > hypersthene > augite > olivine, and a little glass. Accessory iron ore and apatite. Olivine serpentinized.
14	Olivine-basalt.	Upper Ochoa dam site, 200 feet below center line, S. bank of Rio San Juan. Residual boulder in clay forming bluff above hole No. 7; 15 to 25 feet above river.	Megascopically: Dark grey and fine-grained, with small phenocrysts of olivine. Weathers light grey and then ocher yellow. Microscopically: Porphyritic; phenocrysts of olivine in nearly holocrystalline intersertal groundmass. Essential constituents are basic plagioclase (labradorite or anorthite) > pale greenish augite > olivine > glass. Accessory iron ore, apatite, and minute prisms of an undetermined brown mineral.
15–a	Hypersthene-basalt.	Upper Ochoa, bank of Caño Benito; 500 ft. S. of Rio San Juan; residual boulder in red clay.	Megascopically: Dark, heavy, even-textured rock of doleritic aspect. Weathers to an ocherous crust. Microscopically: Nearly holocrystalline doleritic structure. Basic labradorite > augite × hypersthene > glass. Accessory apatite and iron ore. Secondary serpentine, probably from alteration of olivine phenocrysts.
33–a	Basalt (glassy).	Southern point of Tamborcito hills. Exposed at low water on N. bank of Rio San Juan. Coarse volcanic breccia.	Megascopically: Dark and basaltic, with small phenocrysts of feldspar, and green specks of chlorite. Microscopically: Porphyritic structure. Small phenocrysts of basic labradorite or anorthite > augite > iron ore, in a fine groundmass of plagioclase microlites, iron ore and glass. Amygdules of chlorite, and opal (?).
35	Olivine-basalt.	Buena Vista; 3 miles below Boca Sarapiqui cleared hill on N. bank of Rio San Juan. Residual boulder in red clay.	Megascopically: Ordinary olivinitic basalt. Microscopically: Porphyritic with holocrystalline groundmass. Phenocrysts of basic labradorite or anorthite > olivine > augite. Groundmass: Augite >> iron ore > plagioclase. Groundmass is unusually rich in augite. Olivine partly resorbed and usually serpentinized.

Number of Specimen.	Name.	Locality.	Description.
38	Olivine-basalt.	Machado; 1 mile N. 30° W. from Upper Ochoa dam site. Boulder in small brook, nearly in place.	Megascopically: Dark grey, nearly aphanitic. Microscopically: Porphyritic structure. Phenocrysts of olivine $>>$ biotite. Groundmass of augite $>$ plagioclase $\times$ glass $>$ iron ore. Biotite is in ragged plates.
44	Hypersthene-basalt.	San Carlos hills, about 1 mile N. W. of Boca San Carlos, 1000 ft. A. T.; top of bench on a narrow spur. Residual boulder in red clay.	Megascopically: Grey, even-grained, and apparently holocrystalline. Microscopically: Holocrystalline porphyritic structure; phenocrysts grade into groundmass. Essential constituents: basic labradorite $>$ augite $\times$ hypersthene. Accessory iron ore, biotite and apatite.
46	Olivine-basalt.	Castillo; steep rounded hill on S. bank of Rio San Juan. Rock ledge in place.	Megascopically: Minute phenocrysts of feldspar in an aphanitic, dark grey base. Microscopically: Porphyritic structure with fine, rather glassy groundmass. Olivine altered to iddingsite pseudomorphs.
50	Hypersthene-andesite.	Granada; from quarry W. of town; used as a building stone.	Megascopically: Light grey and of porous texture. Microscopically: Porphyritic, with hyalopilitic groundmass. Essential constituents labradorite $>$ augite $\times$ hypersthene $>$ brown hornblende, and abundant glass. Accessory iron ore, apatite and tridymite.
81	Hypersthene-andesite pumice.	Volcano Ometepe; near top of cone on west side. Loose block in ash.	Megascopically: A dark grey, vesicular glass. Microscopically: Phenocrysts of labradorite and hypersthene in a microlitic glass.
82	Hypersthene-andesite.	Volcano Ometepe; large blocks of lava in loose ash at highest point of crater rim.	Megascopically: Nearly black pitchstone, showing small phenocrysts of feldspar. Is somewhat pumiceous. Microscopically: Hyalopilitic structure. Essential constituents are labradorite $>$ hypersthene $>$ augite (in groundmass), with abundant brown glass. A beautifully fresh rock.
84	Olivine-basalt (glassy).	Volcano Ometepe; lava flow on west side near base.	Megascopically: Dark grey vesicular, glassy rock of andesitic aspect. Microscopically: Vesicular and porphyritic structure. Phenocrysts of basic labradorite $>>$ olivine $>$ augite, in a turbid microlitic glass. There is perhaps a little hypersthene present.

Number of Specimen.	Name.	Locality.	Description.
88	Diorite (?) (altered).	Machuca dam site; Campaña island; ½ mile below Machuca. Large boulders at head of island from dike; nearly in place.	Megascopically: Fine-grained, holocrystalline grey rock, with slight porphyritic development of hornblende. Microscopically: An altered holocrystalline granular rock—probably once a diorite. Epidote is very abundant.
91	Quartz-diorite (altered).	Machuca dam site; center line 200 ft. S. of Rio San Juan. Residual boulder in red clay.	Megascopically: A rather fine-grained granular rock of dioritic aspect, with abundant specks of pyrite. Microscopically: An altered quartz diorite, full of secondary minerals. It may have been an augite-diorite originally, as hornblende is green and fibrous.
109	Hypersthene-andesite.	Lake Apoya; inner slope of caldera basin; lava flow associated with ash-beds.	Megascopically: Light grey and porous, with small phenocrysts of plagioclase and hornblende. Microscopically: Porphyritic structure with hyalopilitic groundmass. Phenocrysts of labradorite > hypersthene > greenish augite > hornblende. Groundmass of feldspar laths, augite, iron ore, and much glass.
115	Hypersthene-andesite.	Ravine 1½ miles S. W. of La Flor dam site; dike in Brito sandstone.	Megascopically: Compact dark grey, with numerous small phenocrysts of plagioclase. Microscopically: Porphyritic structure with pilotaxitic groundmass. Phenocrysts of labradorite (Ab_3 An_4) > augite > hypersthene. Augite and hypersthene frequently intergrown. Groundmass consists of same minerals as phenocrysts, with usual accessories and perhaps a little glass.
120	Hypersthene-andesite (vitrophyre).	Rio Grande valley; north side; on Childs route variant II, Sta. 503, near hole No. 4. Rock ledge in place.	Megascopically: Abundant small phenocrysts of plagioclase in nearly black glassy base. Microscopically: Porphyritic structure. Essential constituents are phenocrysts of labradorite (Ab_3 An_4) > hypersthene > augite, in an abundant microlitic brown glass. A fresh and beautiful rock.
123	Hypersthene-basalt (vitrophyric).	Escalante river; about 50 miles N. W. of Brito on the Pacific coast. Residual boulder in black clay soil.	Megascopically: Like above, but apparently a little more weathered. Microscopically: Structure vitrophyric. Essential constituents are labradorite (near Ab_3 An_4) > hypersthene > pale green augite > iron ore, with much microlitic brown glass. Plagioclase shows beautiful skeletal and spherulitic growths. The rock may be a basic facies of a hypersthene andesite, but is rather rich in dark minerals.

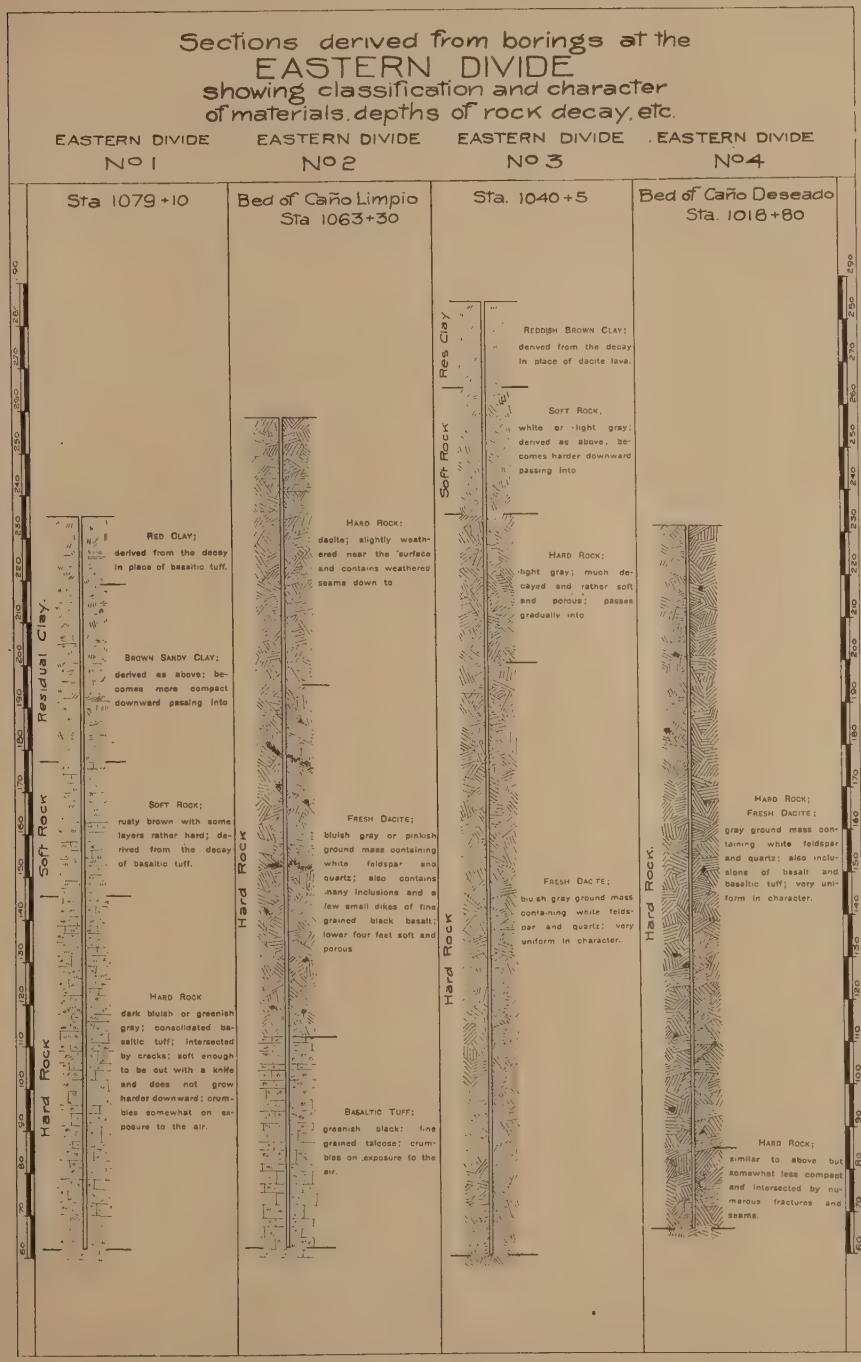
Number of Specimen.	Name.	Locality.	Description.
129	Olivine-basalt.	Palo de Arco; on point of low hill, south bank of Rio San Juan. Residual boulder in red clay.	Megascopically: Nearly black, with phenocrysts of plagioclase and olivine in a compact base. Microscopically: Porphyritic structure, with phenocrysts distinct from groundmass. Phenocrysts of anorthite > olivine > augite. Groundmass a fine intersertal aggregate of augite × plagioclase > iron ore × glass. Olivine is partly serpentinized.
133	Basalt (olivine-free).	Castillo; hill on north bank of Rio San Juan; jointed ledge in place.	Megascopically: Irregularly banded or mottled, aphanitic rock, of somewhat purplish tint. Shows a few minute phenocrysts of feldspar. Microscopically: Porphyritic structure. Small phenocrysts of anorthite and pale augite, in a fine groundmass of plagioclase, augite, iron ore and glass.
135	Aplitic dike-rock.	Pilares rapids; rock ledge in place; exposed at low water in channel of Rio San Juan; dike in Machuca sandstone.	Megascopically: A light grey porphyry with small phenocrysts of feldspar. Microscopically: Porphyritic, with phenocrysts of oligoclase and orthoclase (?), in a fine granular groundmass of alkali feldspar and quartz. A little iron ore and a few biotite scales largely changed to chlorite. Feldspathic phenocrysts are partly changed to calcite. Rock is somewhat obscure. Might be termed an aplite-porphyry.
150-a	Hypersthene-basalt.	El Tigre: N. bank of Rio San Juan, 1½ miles above Boca San Carlos. Residual boulder.	Megascopically: Dark grey and nearly aphanitic. Weathers to an ocherous yellow crust. Microscopically: Essential constituents are labradorite > augite > hypersthene > glass. Usual accessories. Hypersthene partly serpentinized. Some serpentine may have been derived from olivine.
159	Olivine-basalt.	San Carlos embankment; near Caño Cureno, 1¼ miles from lower Ochoa dam site, 150 miles N. E. of No. 7. Rock ledge in place.	Megascopically: Dark grey, and of ordinary basaltic character. Microscopically: Ordinary olivine-basalt, with olivine largely serpentinized.
163-c	Olivine-basalt.	San Francisco hills; N. bank of Rio San Juan, opposite San Francisco island. Residual boulders in red clay.	Megascopically: Dark grey, with small phenocrysts in an aphanitic base. Microscopically: Typical olivine-basalt of nearly holocrystalline doloritic habit.

Number of Specimen.	Name.	Locality.	Description.
167	Hypersthene-basalt.	Tamborcito hills; near Rio San Juan; at various points on crest and sides. Residual boulders in red clay.	Megascopically: Numerous small phenocrysts of plagioclase and pyroxene in a compact, nearly black groundmass. Microscopically: Porphyritic structure. Phenocrysts of basic labrodorite or anorthite > hypersthene, in a fine groundmass of augite, plagioclase and iron ore, with abundant light brown glass.
169	Basalt (olivine-free).	Sarapiqui hills; top of cleared hill, 500 ft. from Rio San Juan, opposite mouth of the Sarapiqui.	Megascopically: Numerous small phenocrysts of plagioclase in a compact dark base. Weathers to an ocherous yellow crust. Microscopical: Porphyritic structure. Phenocrysts of anorthite in a groundmass of plagioclase, augite, iron ore and glass.
173	Basalt (olivine-free).	Punta Petaca; N. bank of Rio San Juan; low cleared hill. Residual boulders in red clay.	Megascopically: Like 169, but more crystalline. Microscopically: Almost holocrystalline doleritic structure. Essential constituents are plagioclase (near bytownite) > augite > iron ore > glass. Accessory apatite.
180	Basalt (probably olivine-basalt).	Caño Deseado; ½ mile above Camp Menocal. Residual boulder in red clay.	Megascopically: Dark and basaltic looking, with abundant small lath-shaped phenocrysts of plagioclase. Weathers to an ocherous crust. Microscopically: Porphyritic structure. Phenocrysts of anorthite > olivine (serpentinized), in a groundmass of plagioclase, augite, iron ore, and glass.
182	Hypersthene-basalt.	Caño Deseado; Camp Warner Miller. Residual boulder in red clay.	Megascopically: Apparently a doleritic basalt. Microscopically: Porphyritic structure. Phenocrysts of basic labradorite or anorthite > augite > hypersthene, in a groundmass of plagioclase > augite > iron ore, and glass. Is apparently near the andesites.
185	Enstatite-andesite.	Falls of Luisa; Caño Deseado; heavy rock ledge in place.	Megascopically: Dark grey, with small phenocrysts of plagioclase augite in a compact groundmass. Microscopically: Porphyritic structure. Phenocrysts of basic labradorite > augite > a rhombic pyroxene (enstatite?), mostly altered to serpentine. Groundmass is hyalopilitic, consisting of plagioclase, augite, rhombic pyroxene and glass, with iron ore and apatite.

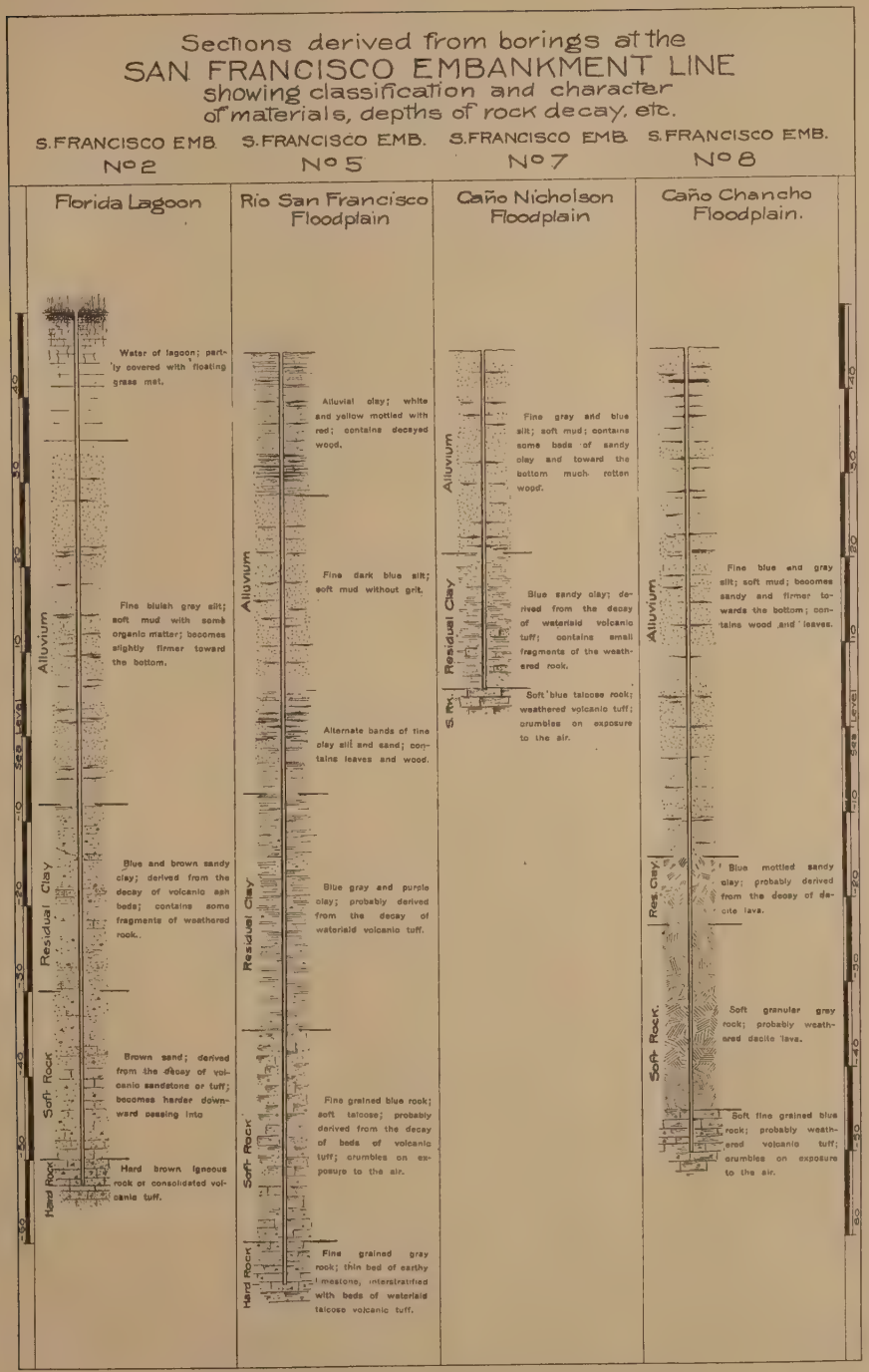
Number of Specimen.	Name.	Locality.	Description.
194	Olivine-basalt.	Silico lake; cut on C. & P. T. Co. Ry., ¼ mile east of the lake. Residual boulders in clay.	Megascopically: Dark and compact, with small phenocrysts of plagioclase and olivine. Microscopically: Ordinary olivine basalt with olivine partly changed to iddingsite.
195	Olivine-basalt.	Silico lake; cut on C. & P. T. Co. Ry., ¼ mile east of lake. Residual boulders in clay; intrusive dikes in 194.	Megascopically: Rather light grey, locally vesicular. Small phenocrysts of plagioclase and olivine in a dense grey groundmass. Microscopically: Like 194.
202	Augite-andesite(?).	Menocal Route; Eastern Divide, core from hole No. 1, 137 feet below surface.	Megascopically: Light grey and glassy, with a few minute dark phenocrysts. Microscopically: Structure porphyritic with hyalopilitic groundmass. Small phenocrysts of plagioclase and pseudomorphs of calcite (after pyroxene?) in a groundmass of feldspar microlites, glass and iron ore. Rock is amygdaloidal and decomposed.
203	Basaltic or andesitic tuff.	Menocal Route; Eastern Divide, core from hole No. 1, 173 feet below surface.	Megascopically: Apparently a dark grey, decomposed, basic tuff. Microscopically: Turbid and glassy. Probably a basaltic tuff, but may be andesitic.
205	Dacite.	Menocal Route; Eastern Divide, core from hole No. 2, 16 feet below surface.	Megascopically: A light grey porphyry showing phenocrysts of feldspar and quartz in a grey glassy base. Microscopically: Porphyritic structure. Phenocrysts of quartz and andesine in a glassy, partly devitrified groundmass resembling the groundmass of many glassy rhyolites. The character of the groundmass and the absence of dark constituents give a decided rhyolitic aspect to the rock as seen in thin section. It is placed provisionally with the dacites on account of its relatively basic plagioclase and absence of sanidine.
206	Dacite.	Menocal Route, Eastern Divide; core from hole No. 2, 100 feet below surface.	Megascopically: Like 205, but contains small inclusions of some darker rock. Microscopically: Very similar to 205, but contains included fragments of pyroxene andesite.
209	Andesite-tuff(?)	Menocal Route, Eastern Divide, core from hole No. 2, 195 feet below surface.	Megascopically: Fragile, grey-green material, apparently a glassy tuff. Microscopically: A fine grained augitic plagioclase tuff—probably andesitic.

Number of Specimen.	Name.	Locality.	Description.
212	Limestone.	San Francisco embankment; between San Francisco and Surprise; core from hole B5, 108 feet below surface.	Megascopically: Light yellow and plainly clastic. Microscopically: A very fine-grained limestone, containing a few specks of iron ore.
216	Basalt or augite-andesite.	Lower Ochoa dam site, center line, N. bank of Rio San Juan; core from hole No. 2, 180 feet below surface.	Megascopically: Like 33. A decomposed chloritized rock. Microscopically: Much decomposed. May have been a basalt or augite andesite.
217	Dacite.	Lower Ochoa dam site; core from hole No. 3; center line S. bank of Rio San Juan; 33 feet below surface.	Megascopically: Dark grey with small phenocrysts of plagioclase and quartz in a compact base. Microscopically: Phenocrysts of labradorite (Ab_1 An_1) and andesine, quartz, and chloritized biotite, in a fine groundmass of plagioclase microlites embedded in a feldspathic base which extinguishes simultaneously over considerable areas of the thin section giving a mottled or micropoikilitic effect with crossed nicols. The rock is not fresh and may have contained some augite. Iron ore and apatite are present as accessories.
219	Olivine-basalt.	Upper Ochoa dam site; core from hole No. 10, 107 feet below surface; top of hill at N. end of dam.	Megascopically: Ordinary appearance of a fine-grained olivine-basalt. Microscopically: Ordinary olivine-basalt, but contains some small brown prisms like those noted in No. 14.
220	Andesite-tuff.	Upper Ochoa dam site; top of hill at N. end of dam; core from hole No. 10, 157 feet below surface.	Megascopically: Somewhat decomposed grey tuff. Microscopically: Apparently a fine andesitic tuff.
223	Dacite.	Upper Ochoa dam site; center line, N. bank of Rio San Juan; core from hole D3, 56 feet below surface.	Megascopically: Light grey, of rhyolitic aspect, carrying small dark inclusions. Microscopically: Porphyritic structure. Phenocrysts of quartz > plagioclase (near andesine) >> green hornblende, in an abundant microlitic and partly devitrified streaky glass. Probably an acid dacite.
226	Olivine-basalt.	Upper Ochoa dam site; top of hill S. end of dam; core from hole No. 9, 84 feet below surface.	Megascopically: Grey, nearly aphanitic, with an occasional small vesicle. Microscopically: An ordinary olivine-basalt, rich in olivine.

Number of Specimen.	Name.	Locality.	Description.
230	Andesitic tuff.	Core from hole No. 180; in channel of Rio San Juan, 1 mile below Machuca.	Megascopically: Apparently a rather fine grey tuff. Microscopically: An andesitic tuff containing fragments of limestone. The limestone shows organic remains.
235	Basalt.	Castillo; core from hole No. 160, head of Castillo rapids; S. side of Rio San Juan; 8 feet below bed of river.	Megascopically: Dark grey and aphanitic. Microscopically: Minute phenocrysts of plagioclase in a fine groundmass made up of plagioclase microlites, some serpentinized ferromagnesian mineral, iron ore, and glass. The rock may possibly belong with the augite andesites.
242	Basalt-amygdaloid.	Toro rapids; core from hole No. 143; S. side of channel of Rio San Juan; opposite mouth of Rio Savalos 10 feet below bed of river.	Megascopically: Weathered brick-red amygdaloid. Microscopically: Probably an amygdaloidal glassy basalt, but original character is obscured by oxidation.
249	Augite-andesite.	Melchorita; core from hole No. 41; in the channel of the Rio San Juan; 2 feet below bed of river.	Megascopically: Dark grey with small phenocrysts of plagioclase and augite. Microscopically: Porphyritic structure. Phenocrysts of labradorite (Ab_3 An_1) > pale greenish augite, in a groundmass of plagioclase, augite, iron ore and glass.
255	Pyroxene-andesite.	Rio Grande valley; core from hole No. 3; Childs Route Variant II, station 495; 35 feet below surface.	Megascopically: Nearly black, with small phenocrysts of plagioclase and augite in a compact groundmass. Microscopically: Porphyritic structure. Phenocrysts of labradorite > augite > rhombic pyroxene (bronzite, or iron-poor hypersthene), in a microlitic, brown glassy base.


Sections derived from borings at the
EASTERN DIVIDE
showing classification and character
of materials, depths of rock decay, etc.
EASTERN DIVIDE No 1
EASTERN DIVIDE No 2
EASTERN DIVIDE No 3
EASTERN DIVIDE No 4
Sta 1079+10
Bed of Caño Limpio Sta 1063+30
Sta. 1040+5
Bed of Caño Deseado Sta. 1018+80
Residual Clay.
Soft Rock
Hard Rock
Res Clay
Soft Rock
Hard Rock
Hard Rock
Red Clay; derived from the decay in place of basaltic tuff.
Brown Sandy Clay; derived as above; becomes more compact downward passing into
Soft Rock; rusty brown with some layers rather hard; derived from the decay of basaltic tuff.
Hard Rock dark bluish or greenish gray; consolidated basaltic tuff; intersected by cracks; soft enough to be cut with a knife and does not grow harder downward; crumbles somewhat on exposure to the air.
Hard Rock; dacite; slightly weathered near the surface and contains weathered seams down to
Fresh Dacite; bluish gray or pinkish ground mass containing white feldspar and quartz; also contains many inclusions and a few small dikes of fine grained black basalt; lower four feet soft and porous
Basaltic Tuff; greenish black; fine grained talcose; crumbles on exposure to the air.
Reddish Brown Clay; derived from the decay in place of dacite lava.
Soft Rock, white or light gray; derived as above, becomes harder downward passing into
Hard Rock; light gray; much decayed and rather soft and porous; passes gradually into
Fresh Dacite; bluish gray ground mass containing white feldspar and quartz; very uniform in character.
Hard Rock; Fresh Dacite; gray ground mass containing white feldspar and quartz; also inclusions of basalt and basaltic tuff; very uniform in character.
Hard Rock; similar to above but somewhat less compact and intersected by numerous fractures and seams.

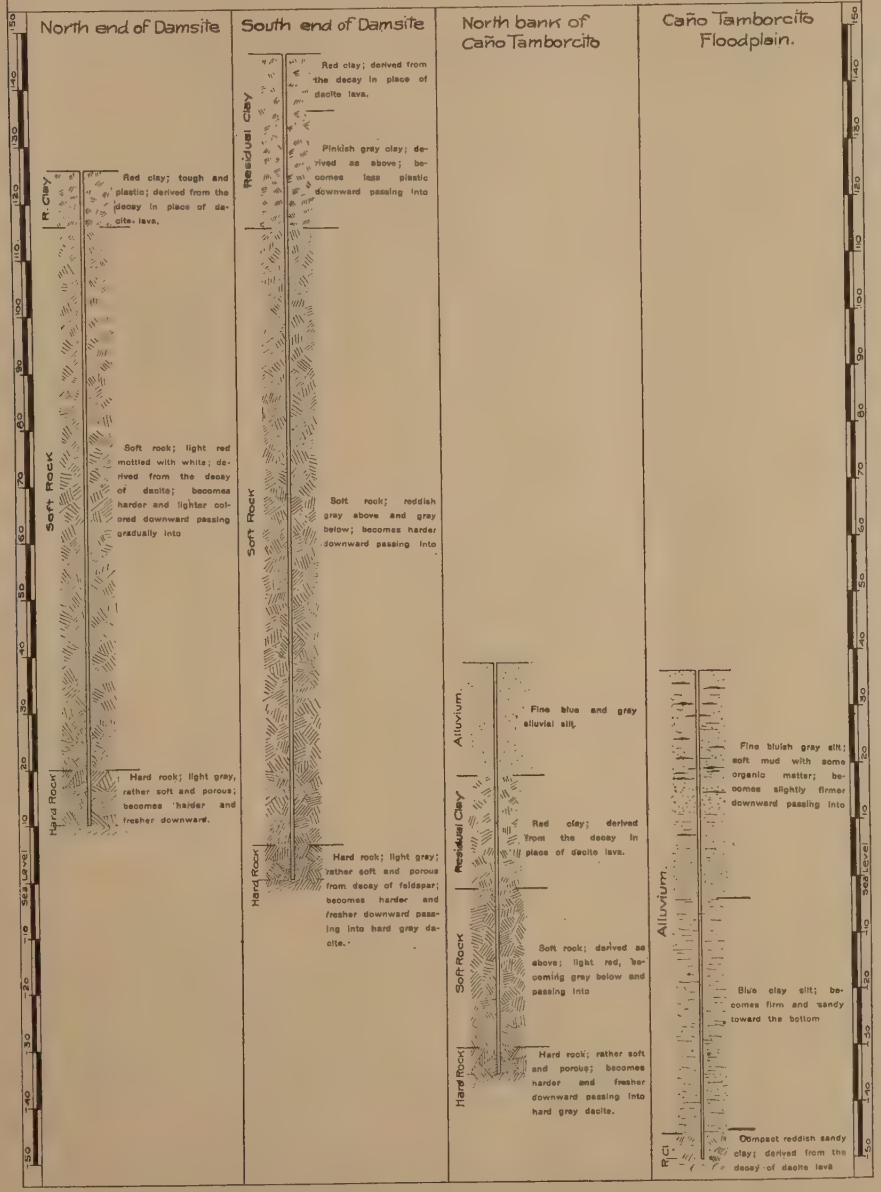
DRILL SECTIONS—EASTERN DIVIDE.


Sections derived from borings at the
SAN FRANCISCO EMBANKMENT LINE
showing classification and character
of materials, depths of rock decay, etc.
S. FRANCISCO EMB. No 2
S. FRANCISCO EMB. No 5
S. FRANCISCO EMB. No 7
S. FRANCISCO EMB. No 8
Florida Lagoon
Rio San Francisco Floodplain
Caño Nicholson Floodplain
Caño Chancho Floodplain.
Water of lagoon; partly covered with floating grass mat.
Fine bluish grey silt; soft mud with some organic matter; becomes slightly firmer toward the bottom.
Blue and brown sandy clay; derived from the decay of volcanic ash beds; contains some fragments of weathered rock.
Brown sand; derived from the decay of volcanic sandstone or tuff; becomes harder downward passing into
Hard brown igneous rock or consolidated volcanic tuff.
Alluvial clay; white and yellow mottled with red; contains decayed wood.
Fine dark blue silt; soft mud without grit.
Alternate bands of fine clay silt and sand; contains leaves and wood.
Blue gray and purple clay; probably derived from the decay of waterlaid volcanic tuff.
Fine grained blue rock; soft talcose; probably derived from the decay of beds of volcanic tuff; crumbles on exposure to the air.
Fine grained gray rock; thin bed of earthy limestone, interstratified with beds of waterlaid talcose volcanic tuff.
Fine gray and blue silt; soft mud; contains some beds of sandy clay and toward the bottom much rotten wood.
Blue sandy clay; derived from the decay of waterlaid volcanic tuff; contains small fragments of the weathered rock.
Soft blue talcose rock; weathered volcanic tuff; crumbles on exposure to the air.
Fine blue and grey silt; soft mud; becomes sandy and firmer towards the bottom; contains wood and leaves.
Blue mottled sandy clay; probably derived from the decay of dacite lava.
Soft granular grey rock; probably weathered dacite lava.
Soft fine grained blue rock; probably weathered volcanic tuff; crumbles on exposure to the air.
Alluvium
Residual Clay
Soft Rock
Hard Rock
S. Rk.
Res. Clay
Sea Level

DRILL SECTIONS—SAN FRANCISCO EMBANKMENT.

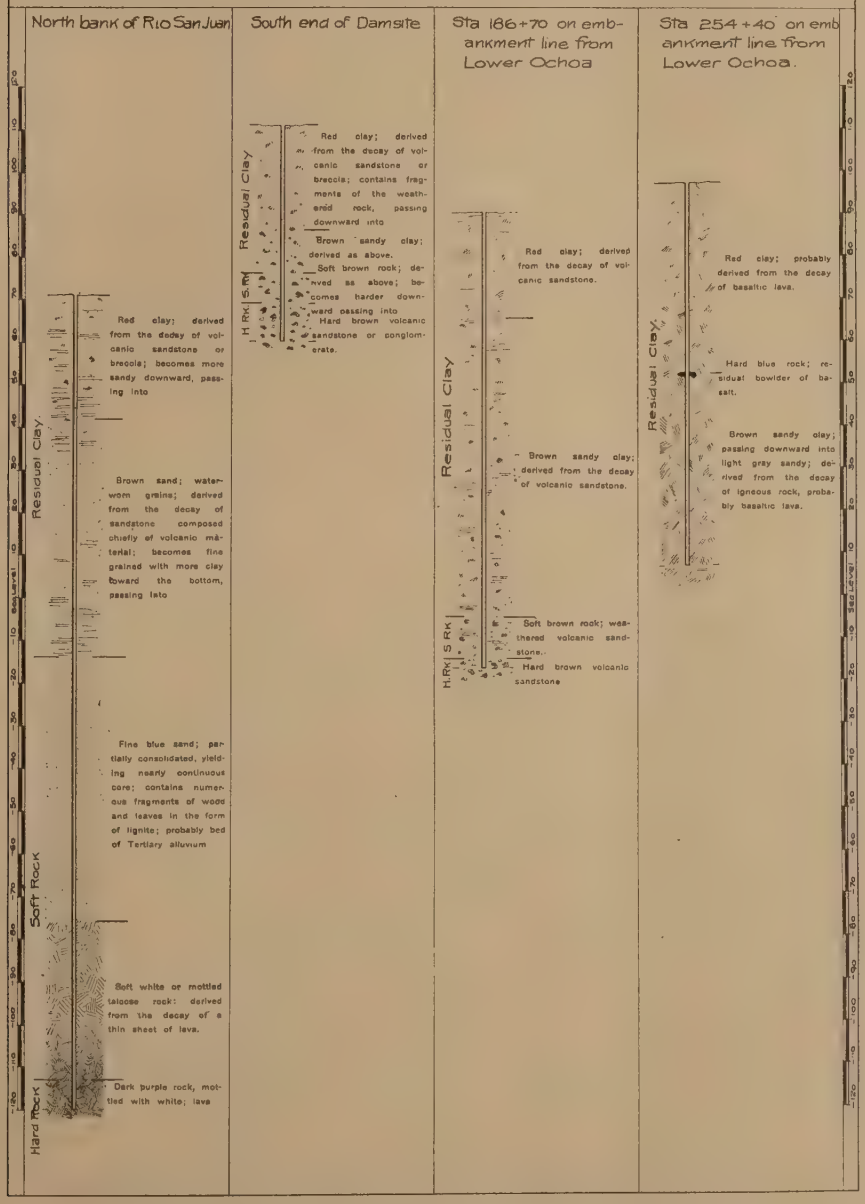
Sections derived from borings at the TAMBOR GRANDE DAMSITE AND TAMBORCITO EMBANKMENT LINE showing classification and character of materials, depths of rock decay, etc.

TAMBOR GRANDE No 1. | TAMBOR GRANDE No 4 | TAMBORCITO No 1 | TAMBORCITO No 3


North end of Damsite
R. Clay
Red clay; tough and plastic; derived from the decay in place of dacite lava.
Soft Rock
Soft rock; light red mottled with white; derived from the decay of dacite; becomes harder and lighter colored downward passing gradually into
Hard Rock
Hard rock; light gray, rather soft and porous; becomes harder and fresher downward.
South end of Damsite
Residual Clay
Red clay; derived from the decay in place of dacite lava.
Pinkish gray clay; derived as above; becomes less plastic downward passing into
Soft Rock
Soft rock; reddish gray above and gray below; becomes harder downward passing into
Hard Rock
Hard rock; light gray; rather soft and porous from decay of feldspar; becomes harder and fresher downward passing into hard gray dacite.
North bank of Caño Tamborcito
Alluvium.
Fine blue and gray alluvial silt.
Residual Clay
Red clay; derived from the decay in place of dacite lava.
Soft Rock
Soft rock; derived as above; light red, becoming gray below and passing into
Hard Rock
Hard rock; rather soft and porous; becomes harder and fresher downward passing into hard gray dacite.
Caño Tamborcito Floodplain.
Alluvium.
Fine bluish gray silt; soft mud with some organic matter; becomes slightly firmer downward passing into
Blue clay silt; becomes firm and sandy toward the bottom
R.C.
Compact reddish sandy clay; derived from the decay of dacite lava
Sea Level

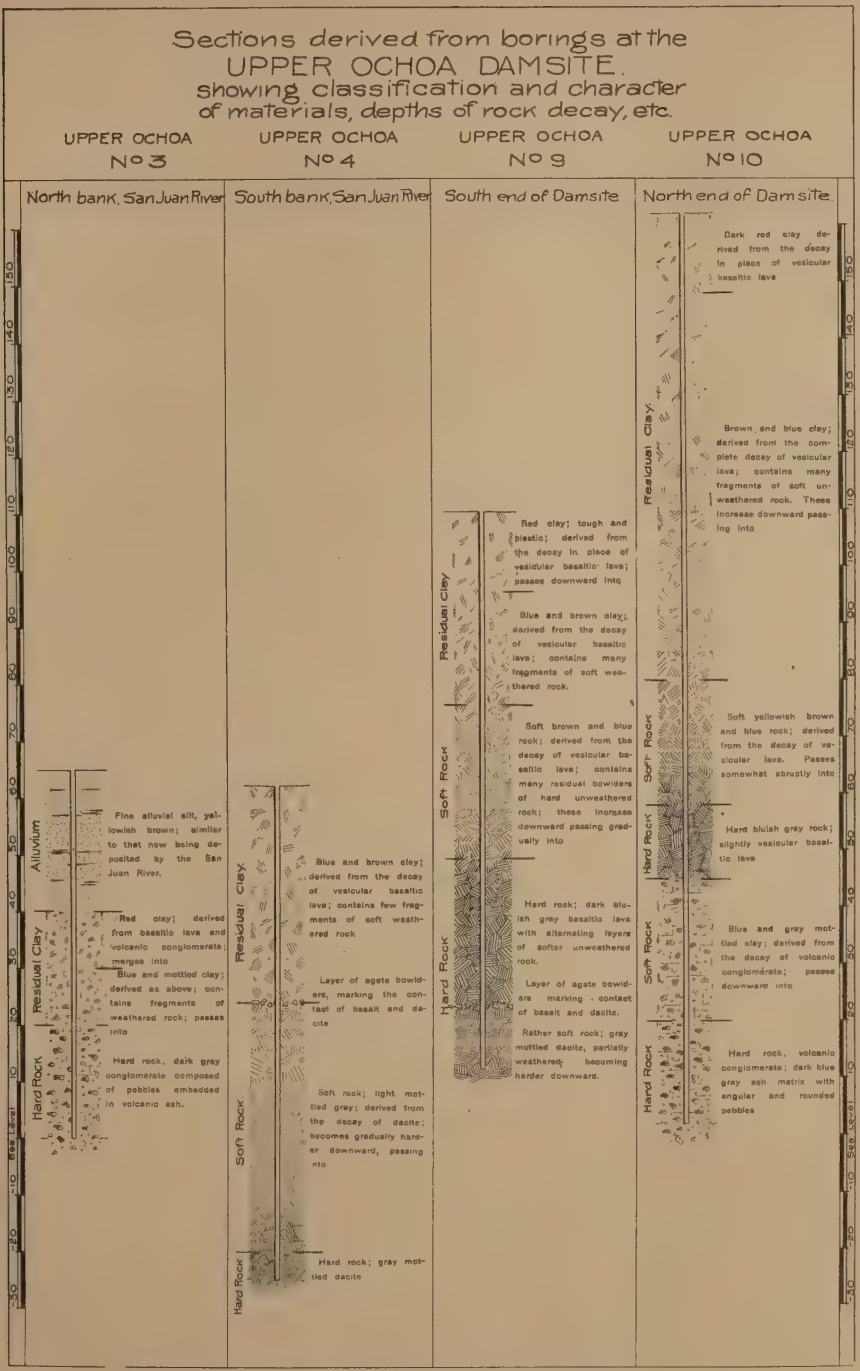
DRILL SECTIONS—TAMBOR GRANDE AND TAMBORCITO.

Sections derived from borings at the LOWER OCHOA DAMSITE AND SAN CARLOS EMBANKMENT LINE showing classification and character of materials, depths of rock decay, etc.


LOWER OCHOA No 2
North bank of Rio San Juan
Residual Clay
Red clay; derived from the decay of volcanic sandstone or breccia; becomes more sandy downward, passing into
Brown sand; water-worn grains; derived from the decay of sandstone composed chiefly of volcanic material; becomes fine grained with more clay toward the bottom, passing into
Soft Rock
Fine blue sand; partially consolidated, yielding nearly continuous core; contains numerous fragments of wood and leaves in the form of lignite; probably bed of Tertiary alluvium
Soft white or mottled talcose rock; derived from the decay of a thin sheet of lava.
Hard Rock
Dark purple rock, mottled with white; lava
LOWER OCHOA No 4
South end of Damsite
Residual Clay
H.Rk
S.Rk
Red clay; derived from the decay of volcanic sandstone or breccia; contains fragments of the weathered rock, passing downward into
Brown sandy clay; derived as above.
Soft brown rock; derived as above; becomes harder downward passing into
Hard brown volcanic sandstone or conglomerate.
SAN CARLOS EMB. No 3
Sta 186+70 on embankment line from Lower Ochoa
Residual Clay
H.Rk
S.Rk
Red clay; derived from the decay of volcanic sandstone.
Brown sandy clay; derived from the decay of volcanic sandstone.
Soft brown rock; weathered volcanic sandstone.
Hard brown volcanic sandstone
SAN CARLOS EMB. No 7
Sta 254+40 on embankment line from Lower Ochoa.
Residual Clay
Red clay; probably derived from the decay of basaltic lava.
Hard blue rock; residual bowlder of basalt.
Brown sandy clay; passing downward into light gray sandy; derived from the decay of igneous rock, probably basaltic lava.
Sea Level

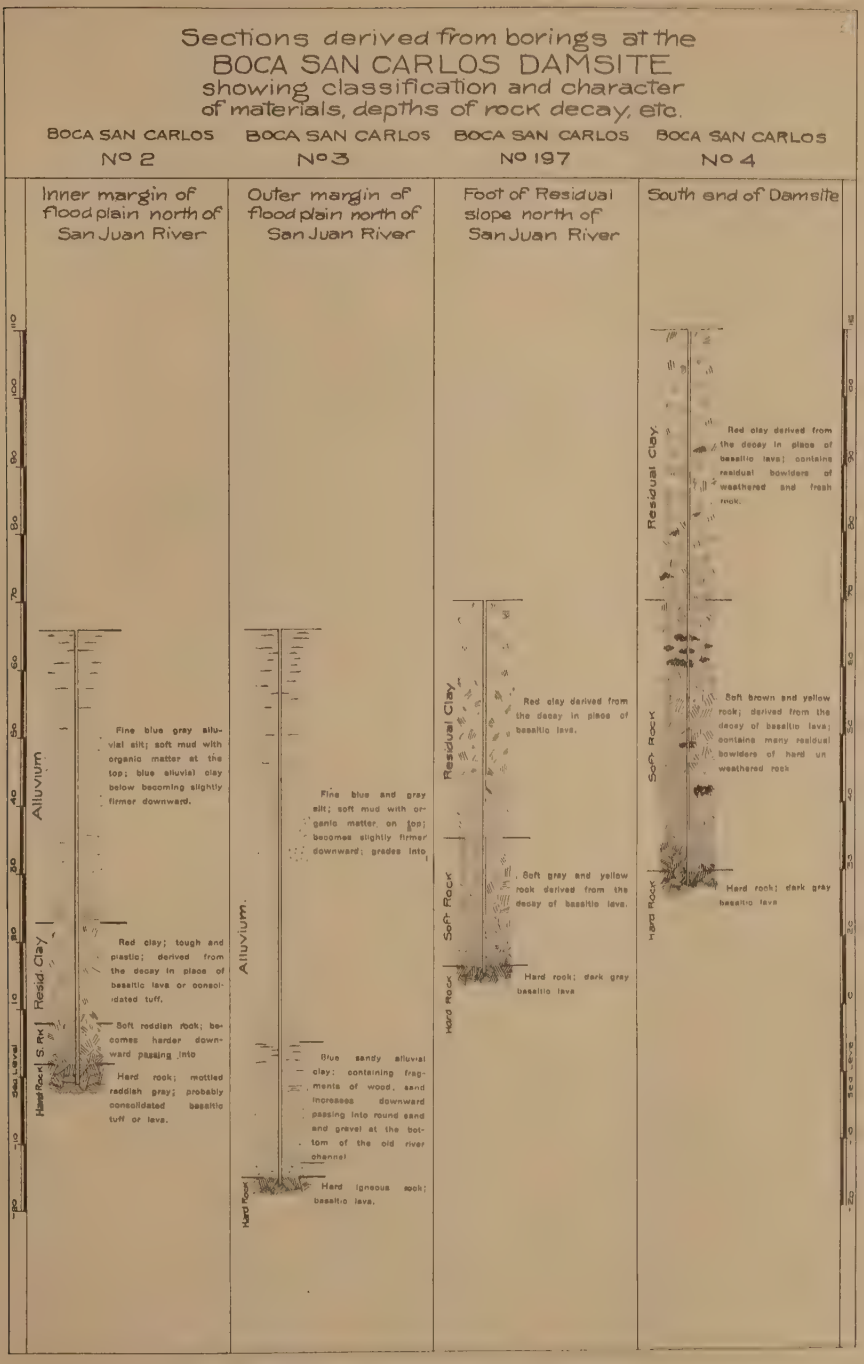
DRILL SECTIONS—LOWER OCHOA AND SAN CARLOS EMBANKMENT.

Sections derived from borings at the UPPER OCHOA DAMSITE, showing classification and character of materials, depths of rock decay, etc.

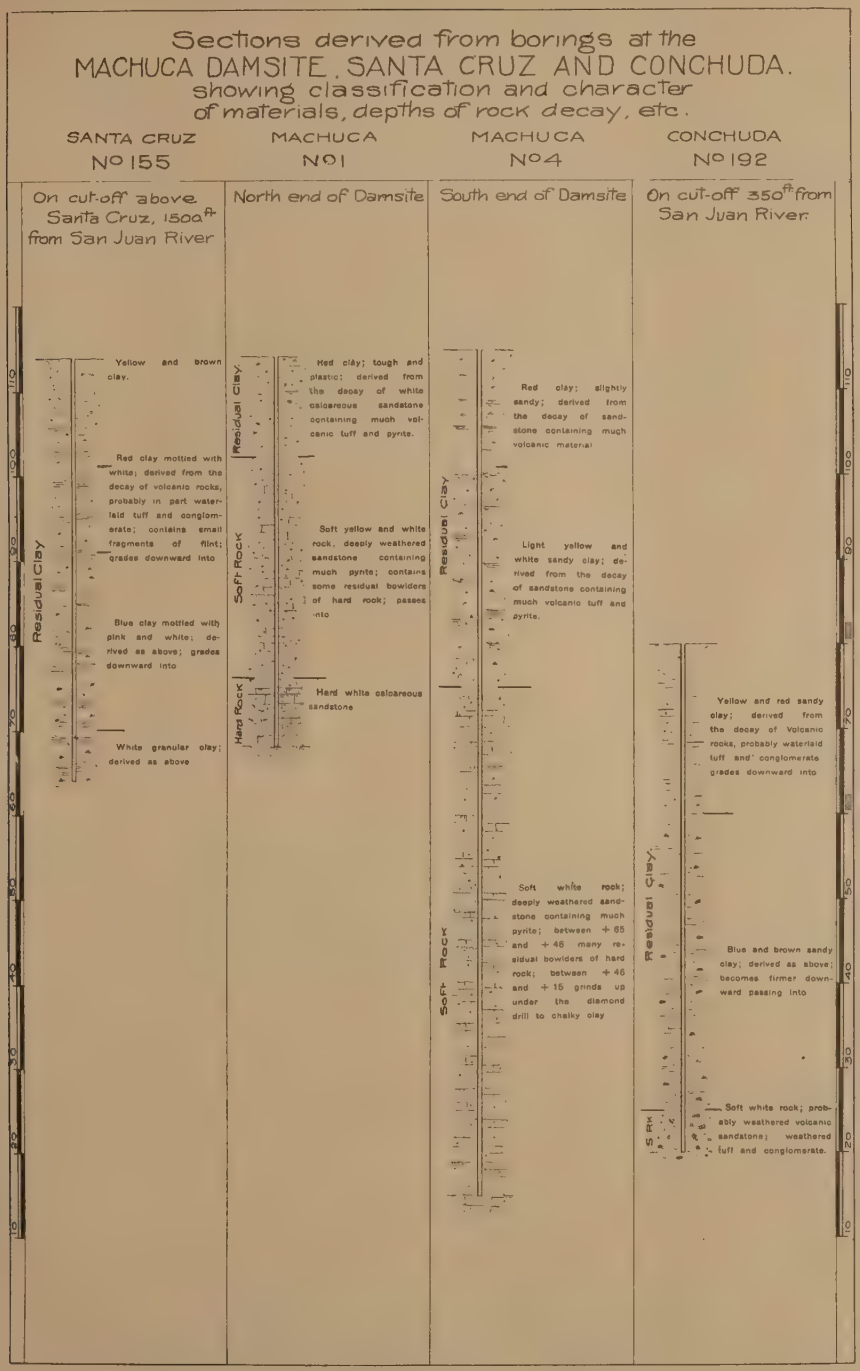

UPPER OCHOA No 3
UPPER OCHOA No 4
UPPER OCHOA No 9
UPPER OCHOA No 10
North bank, San Juan River
South bank, San Juan River
South end of Damsite
North end of Damsite
Alluvium
Residual Clay
Hard Rock
Soft Rock
Fine alluvial silt, yellowish brown; similar to that now being deposited by the San Juan River.
Red clay; derived from basaltic lava and volcanic conglomerate; merges into
Blue and mottled clay; derived as above; contains fragments of weathered rock; passes into
Hard rock, dark gray conglomerate composed of pebbles embedded in volcanic ash.
Blue and brown clay; derived from the decay of vesicular basaltic lava; contains few fragments of soft weathered rock
Layer of agate bowlders, marking the contact of basalt and dacite
Soft rock; light mottled gray; derived from the decay of dacite; becomes gradually harder downward, passing into
Hard rock; gray mottled dacite
Red clay; tough and plastic; derived from the decay in place of vesicular basaltic lava; passes downward into
Blue and brown clay; derived from the decay of vesicular basaltic lava; contains many fragments of soft weathered rock.
Soft brown and blue rock; derived from the decay of vesicular basaltic lava; contains many residual bowlders of hard unweathered rock; these increase downward passing gradually into
Hard rock; dark bluish gray basaltic lava with alternating layers of softer unweathered rock.
Layer of agate bowlders marking contact of basalt and dacite.
Rather soft rock; gray mottled dacite, partially weathered; becoming harder downward.
Dark red clay derived from the decay in place of vesicular basaltic lava
Brown and blue clay; derived from the complete decay of vesicular lava; contains many fragments of soft unweathered rock. These increase downward passing into
Soft yellowish brown and blue rock; derived from the decay of vesicular lava. Passes somewhat abruptly into
Hard bluish grey rock; slightly vesicular basaltic lava
Blue and gray mottled clay; derived from the decay of volcanic conglomerate; passes downward into
Hard rock, volcanic conglomerate; dark blue gray ash matrix with angular and rounded pebbles
Mean Sea Level

DRILL SECTIONS—UPPER OCHOA.

Sections derived from borings at the BOCA SAN CARLOS DAMSITE showing classification and character of materials, depths of rock decay, etc.


BOCA SAN CARLOS No 2
Inner margin of flood plain north of San Juan River
Alluvium
Resid. Clay
S. Rk.
Hard Rock
Sea Level
Fine blue gray alluvial silt; soft mud with organic matter at the top; blue alluvial clay below becoming slightly firmer downward.
Red clay; tough and plastic; derived from the decay in place of basaltic lava or consolidated tuff.
Soft reddish rock; becomes harder downward passing into
Hard rock; mottled reddish gray; probably consolidated basaltic tuff or lava.
BOCA SAN CARLOS No 3
Outer margin of flood plain north of San Juan River
Alluvium
Hard Rock
Fine blue and gray silt; soft mud with organic matter on top; becomes slightly firmer downward; grades into
Blue sandy alluvial clay; containing fragments of wood, sand increases downward passing into round sand and gravel at the bottom of the old river channel
Hard igneous rock; basaltic lava.
BOCA SAN CARLOS No 197
Foot of Residual slope north of San Juan River
Residual Clay
Soft Rock
Hard Rock
Red clay derived from the decay in place of basaltic lava.
Soft gray and yellow rock derived from the decay of basaltic lava.
Hard rock; dark gray basaltic lava
BOCA SAN CARLOS No 4
South end of Damsite
Residual Clay
Soft Rock
Hard Rock
Red clay derived from the decay in place of basaltic lava; contains residual bowlders of weathered and fresh rock.
Soft brown and yellow rock; derived from the decay of basaltic lava; contains many residual bowlders of hard unweathered rock
Hard rock; dark gray basaltic lava

DRILL SECTIONS—BOCA SAN CARLOS.


Sections derived from borings at the
MACHUCA DAMSITE, SANTA CRUZ AND CONCHUDA.
showing classification and character
of materials, depths of rock decay, etc.
SANTA CRUZ
No 155
MACHUCA
No 1
MACHUCA
No 4
CONCHUDA
No 192
On cut-off above Santa Cruz, 1500 ft from San Juan River
North end of Damsite
South end of Damsite
On cut-off 350 ft from San Juan River
Residual Clay
Yellow and brown clay.
Red clay mottled with white; derived from the decay of volcanic rocks, probably in part water-laid tuff and conglomerate; contains small fragments of flint; grades downward into
Blue clay mottled with pink and white; derived as above; grades downward into
White granular clay; derived as above
Residual Clay
Soft Rock
Hard Rock
Red clay; tough and plastic; derived from the decay of white calcareous sandstone containing much volcanic tuff and pyrite.
Soft yellow and white rock, deeply weathered sandstone containing much pyrite; contains some residual bowlders of hard rock; passes into
Hard white calcareous sandstone
Residual Clay
Soft Rock
Red clay; slightly sandy; derived from the decay of sandstone containing much volcanic material
Light yellow and white sandy clay; derived from the decay of sandstone containing much volcanic tuff and pyrite.
Soft white rock; deeply weathered sandstone containing much pyrite; between +65 and +46 many residual bowlders of hard rock; between +46 and +15 grinds up under the diamond drill to chalky clay
Residual Clay
S. Rk
Yellow and red sandy clay; derived from the decay of volcanic rocks, probably waterlaid tuff and conglomerate; grades downward into
Blue and brown sandy clay; derived as above; becomes firmer downward passing into
Soft white rock; probably weathered volcanic sandstone; weathered tuff and conglomerate.
110
100
90
80
70
60
50
40
30
20
10

DRILL SECTIONS—MACHUCA, SANTA CRUZ AND CONCHUDA.

SECTIONS SHOWING RELATIONS OF PRESENT RIVERS TO THEIR FLOODPLAINS AND FORMER CHANNELS

SCALES
Vertical 1in. = 150ft.
Horizontal 1in. = 8450ft.

C.W. HAYES U.S.G.S.

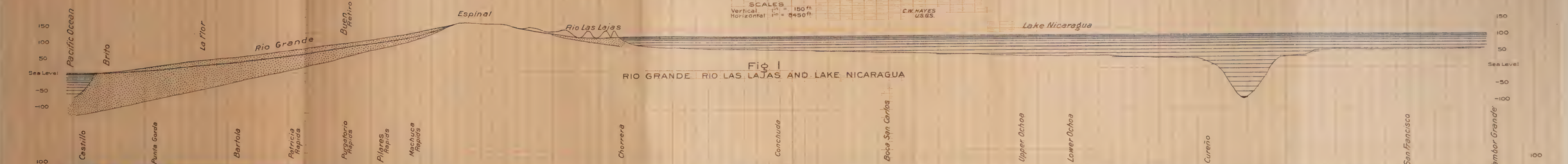


Fig 1
RIO GRANDE RIO LAS LAJAS AND LAKE NICARAGUA

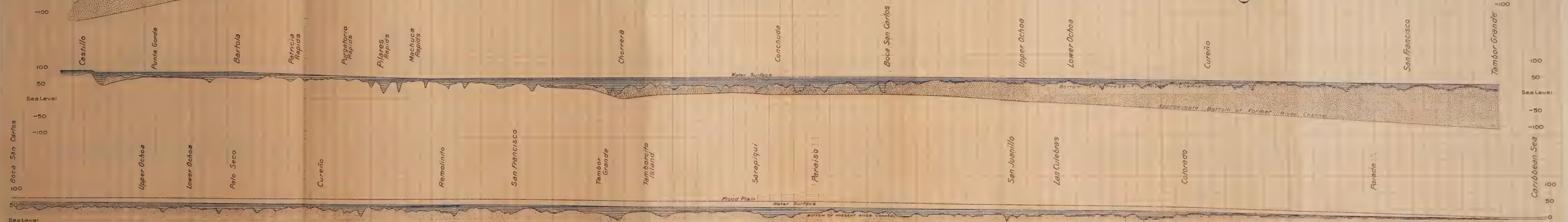


Fig 2
RIO SAN JUAN

THE FRIEDENWALD CO
LITHOGRAPHERS
BALTIMORE MD.

GEOLOGICAL SECTIONS

FROM THE CARIBBEAN SEA TO THE PACIFIC OCEAN APPROXIMATELY ON THE LINE OF THE PROPOSED NICARAGUA CANAL.

SCALES: Vertical 1" = 3000ft Horizontal 1" = 6000ft

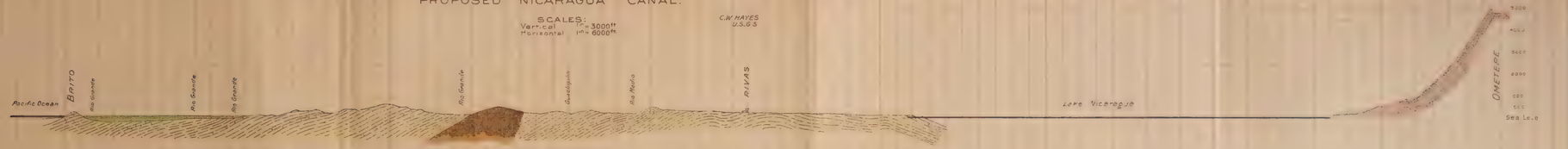
C.W. HAYES U.S.G.S.

RECENT.

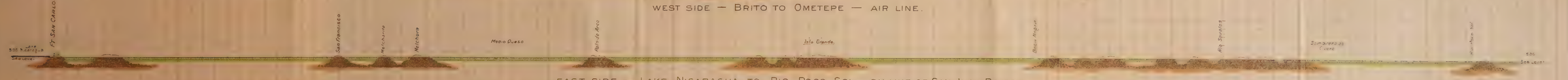
- Alluvium
- Volcanic tuffs and lavas.

TERTIARY.

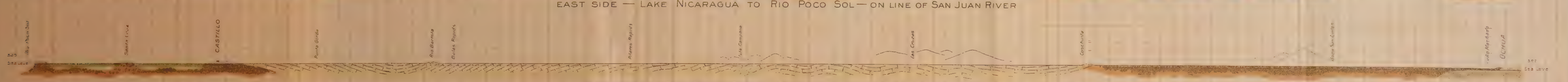
- Brito and Machuca formations
- Volcanic tuffs and Conglomerates
- Dacite
- Basalt and Andesite



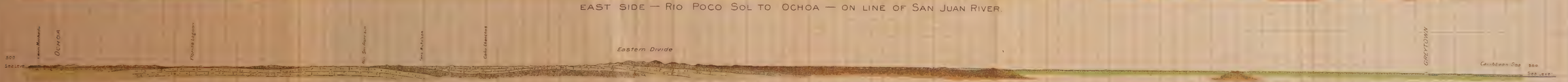
WEST SIDE — BRITO TO OMETEPE — AIR LINE.



EAST SIDE — LAKE NICARAGUA TO RIO POCO SOL — ON LINE OF SAN JUAN RIVER



EAST SIDE — RIO POCO SOL TO OCHOA — ON LINE OF SAN JUAN RIVER.



EAST SIDE — OCHOA TO GREYTOWN — MENOCAL ROUTE.

THE FRIEDENWALD CO. LITH. BALTIMORE

GEOLOGICAL SECTIONS AT VARIOUS DAM SITES

IN THE RIO GRANDE VALLEY.

SCALES

Vertical 1 in. = 100 ft.
Horizontal 1 in. = 200 ft.

LA FLOR
Fig 1

BUENO RETIRO
Fig 2

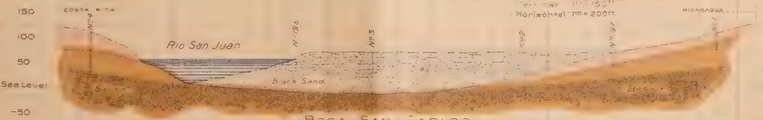
Alluvium Clay silt and Sand.
Residual Clay.
Brito and Machuca formations.
Volcanic tuff and conglomerate.
Dacite.
Basalt and Andesite.

IN THE SAN JUAN VALLEY

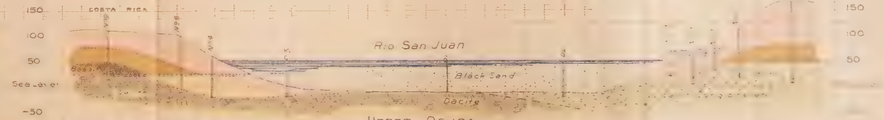
SCALES

Vertical 1 in. = 100 ft.
Horizontal 1 in. = 200 ft.

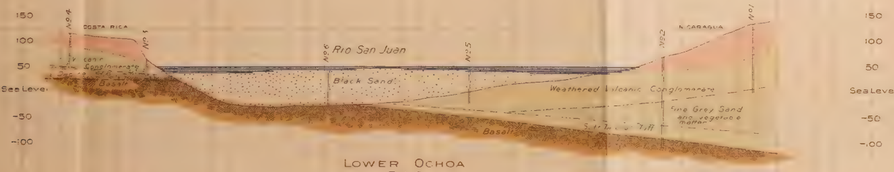
LOWER MACHUCA
Fig 3



BOCA SAN CARLOS
Fig 4



UPPER OCHOA
Fig 5

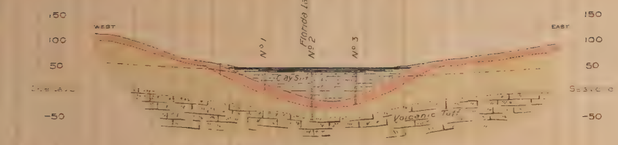


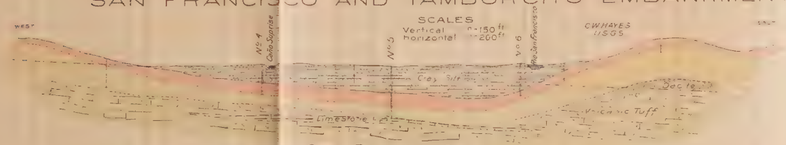
LOWER OCHOA
Fig 6

TAMBOR GRAND
Fig 7

GEOLOGICAL SECTIONS OF PORTIONS OF THE SAN FRANCISCO AND TAMBORCITO EMBANKMENTS.

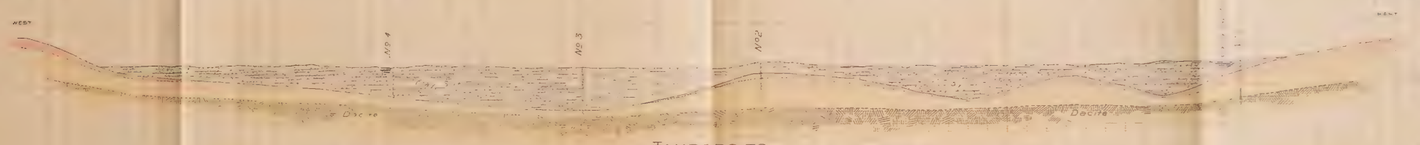
SCALES
Vertical 1" = 150 ft
Horizontal 1" = 200 ft



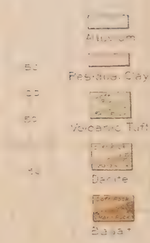
FLORIDA LAGOON
Fig 1

SAN FRANCISCO
Fig 2

NICHOLSON
Fig 3.

CHANCHOS
Fig 4



TAMBORCITO
Fig 5



GEOLOGICAL SECTION OF THE EASTERN DIVIDE

SCALES
Vertical 1" = 300' Horizontal 1" = 400'

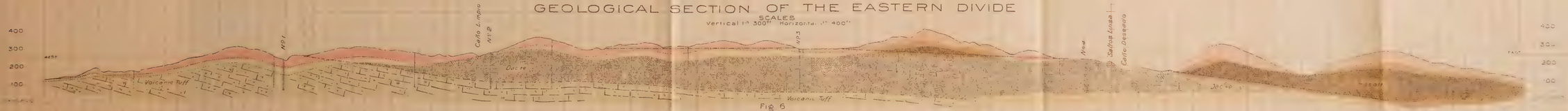


Fig 6

APPENDIX III

REPORT

OF

HYDROGRAPHIC INVESTIGATIONS IN NICARAGUA

MADE FOR THE

NICARAGUA CANAL COMMISSION

BY

ARTHUR P. DAVIS
Hydrographer

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APPENDIX III

The Hydrographic and Meteorologic information required by the Nicaragua Canal Commission relates to three principal objects:

1. The water supply for the use and leakage of the canal.

2. The quantity of rainfall and volume of streams, considered as obstacles to construction.

3. The volume and habit of excessive floods, with reference to their permanent control and discharge without injury to the canal or other property.

The desired information therefore required an investigation of the discharge of all streams of importance which it was proposed to control during construction or for which it was necessary to provide diversion channels or spillways; and measurements of rainfall at points as widely distributed as possible throughout the basin of Lake Nicaragua.

It also required an approximate determination of the rate of evaporation on Lake Nicaragua, and some investigation of the sediment carried by the larger rivers.

STREAM MEASUREMENTS.

The general method used in observing the regimen and discharge of streams is substantially as follows:

A point is selected as near as may be to the location at which knowledge is desired, having reference to the conditions of the stream itself, the aim being to secure high permanent banks on both sides of the river, a straight channel as uniform in depth and velocity as may be, and avoiding any location which is a short distance above an important tributary, and which for this reason might be affected in the matter of back water by floods in that tributary. A gage is placed in the stream near one bank, graduated to feet and tenths, and so situated if possible as to be read conveniently from the shore. It is usually possible to fasten such a gage in deep water to the trunk of an overhanging tree and in a vertical position. The height of water indicated by this gage is read and recorded usually twice every day, and the mean of the two readings taken as the mean gage height for that date. At various intervals, depending upon the facilities available and the change of gage height, measurements of discharge are made with a current meter. Soundings are taken at known distances from an assumed initial point and the velocity measured by submerging an electric current meter at six-tenths of the measured depth, and holding it in that position for a length of time sufficient to make a good determination of the velocity at that point, usually 100 seconds or more. This operation is repeated at short intervals for the entire width of the stream, and from these observations the discharge in cubic feet per second is computed for each section by multiplying the depth, width and measured velocity together. The discharge of the several sections being added together form a

result for the discharge of the entire stream. At the beginning and end of the gaging a careful note is made of the stage of the water indicated on the river gage, and the mean of those two observations is taken as the mean gage height at the time of observation. It is the effort to have such observations well distributed with reference to the height of water in the river, in order to show the relation of the indications of the gage rod to the actual discharge of the stream. This relation is found to be reasonably definite and uniform for most of the streams, and by plotting the gage heights as ordinates and the discharge results as abscissas their general relation is established and a curve drawn, satisfying as nearly as possible all the observations made.

Brito Station on Rio Grande.

This station was established by D. H. Baldwin on January 8, about 1 mile below La Flor dam site on Rio Grande, just below where the stream bends to the north.

A cable and gaging car were put in place for taking measurements. The gage was driven in the bed of the river near the left bank, and the top fastened to the tagged wire. As this was deemed insecure, a new gage was put in place on January 22 about two hundred feet farther upstream, which was driven into the clay bottom, and spiked to a tree growing on the bank. When the old gage read 1.85 the new gage read 3.38. The readings are here reduced to the datum of the new gage.

The channel begins to curve a short distance above the station. The left bank is high and steep. The right may sometimes overflow at high water. Later operations by the surveying parties having shown the desirability of measurements of Rio Tola, the Rio Grande station was removed June 13, to a point below the mouth of Rio Tola, in order that both streams could be observed from one camp. It is about 300 yards below the junction of the Tola and Rio Grande. The gage is a vertical rod divided to feet and tenths, and fastened to an overhanging tree on the left bank of the river. Near this point the cable is stretched across the river, upon which runs a gaging car from which measurements are made, a tagged wire being stretched alongside.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO GRANDE BELOW MOUTH OF THE TOLA.

Date. 1898	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. feet).	Mean velocity (feet per sec.).	Discharge (second-feet).	Remarks.
Jan. 9	D. H. Baldwin	....	3.48	59	1.36	80	
" 22	A. P. Davis	94	3.44	56	1.11	62	
June 4	"	94	2.95	26	0.68	18	
July 2	D. H. Baldwin	1984	3.18	68	2.35	161	New gage-rod reads, .35′ less.
" 30	"	1984	6.80	315	4.15	1,306	
Aug. 10	"	1984	2.40	70	0.92	65	
" 21	"	1984	4.30	164	2.93	481	
Sep. 14	"	1984	3.78	124	2.73	339	
" 21	"	Float.	11.10	606	4.55	2,758	
" 29	"	1984	4.00	144	2.94	423	
Oct. 8	H. C. Hurd	Float.	3.60	122	2.33	285	
" 9	"	"	5.92	275	3.98	1,092	
" 10	"	"	5.00	213	3.38	718	
" 15	"	"	8.80	474	4.28	2,026	
" 27	"	Meter B. & B. No. 1.	4.25	163	4.12	675	Velocity taken at .5 depth.
Nov. 28	"	1	3.32	88	2.83	249	" " "
Dec. 13	"	1	2.99	69	2.50	172	" " "

GAGING STATION ON RIO GRANDE, AT BRITO.

RATING TABLE FOR RIO GRANDE BELOW MOUTH OF THE TOLA.

This table is applicable only from January 6, 1898, to June 13, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.
2.7	9	3.1	35	3.5	75	3.9	115	4.3	155
2.8	12	3.2	45	3.6	85	4.0	125	...	...
2.9	17	3.3	55	3.7	95	4.1	135	...	...
3.0	25	3.4	65	3.8	105	4.2	145	...	...

RATING TABLE FOR RIO GRANDE BELOW MOUTH OF THE TOLA.

This table is applicable only from June 13, 1898, to December 31, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
1.6	12	3.6	261	5.6	892	7.6	1,575	9.6	2,275
1.7	13	3.7	287	5.7	926	7.7	1,610	9.7	2,310
1.8	14	3.8	314	5.8	960	7.8	1,645	9.8	2,345
1.9	16	3.9	342	5.9	994	7.9	1,680	9.9	2,380
2.0	20	4.0	371	6.0	1,028	8.0	1,715	10.0	2,415
2.1	27	4.1	401	6.1	1,062	8.1	1,750	10.1	2,450
2.2	35	4.2	432	6.2	1,096	8.2	1,785	10.2	2,485
2.3	44	4.3	464	6.3	1,130	8.3	1,820	10.3	2,520
2.4	54	4.4	496	6.4	1,164	8.4	1,855	10.4	2,555
2.5	65	4.5	528	6.5	1,198	8.5	1,890	10.5	2,590
2.6	77	4.6	560	6.6	1,232	8.6	1,925	10.6	2,625
2.7	90	4.7	592	6.7	1,266	8.7	1,960	10.7	2,660
2.8	104	4.8	625	6.8	1,300	8.8	1,995	10.8	2,695
2.9	119	4.9	658	6.9	1,334	8.9	2,030	10.9	2,730
3.0	135	5.0	691	7.0	1,368	9.0	2,065	11.0	2,765
3.1	152	5.1	724	7.1	1,402	9.1	2,100	11.1	2,800
3.2	170	5.2	757	7.2	1,436	9.2	2,135	11.2	2,835
3.3	190	5.3	790	7.3	1,470	9.3	2,170	11.3	2,870
3.4	212	5.4	824	7.4	1,505	9.4	2,205	11.4	2,905
3.5	236	5.5	858	7.5	1,540	9.5	2,240	....	....

ESTIMATED MONTHLY DISCHARGE OF RIO GRANDE BELOW MOUTH OF THE TOLA.

Month.	Discharge in Second-Feet.			Total in Acre-Feet.	Month.	Discharge in Second-Feet.			Total in Acre-Feet
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
1898.					1898.				
									Brought forward, 17,970
January (6–31) ...	75	60	69	3,340	July	2,030	55	121	7,440
February	55	41	49	2,720	August	145	45	67	4,120
March	40	25	35	2,150	September	2,975	55	253	15,050
April	35	17	25	1,490	October	2,065	260	596	36,650
May	85	17	28	1,720	November	1,028	190	282	16,780
June	1,990	17	110	6,550	December	190	97	130	7,990
				17,970	Total				106,000

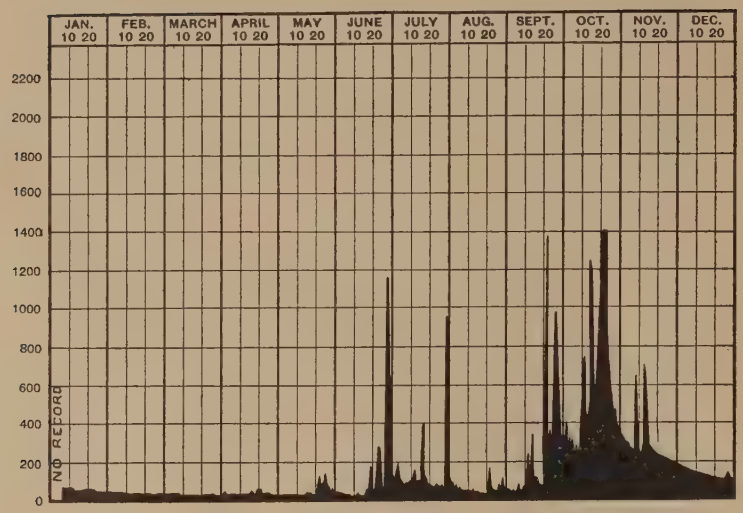


FIG. 1. Diagram of Daily Discharge of Rio Grande, 1898.

LIST OF MEASUREMENTS MADE ON RIO TOLA, ¾ MILE ABOVE ITS MOUTH.

No.	Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge (second-feet).	Remarks.
1	July 2....	D. H. Baldwin....	1984	2.21	48.1	1.41	68	
2	Aug 10....	"	1984	1.60	29.4	0.95	28	
3	" 21....	"	1984	2.80	28.1	2.16	61	
4	" 29....	"	1984	4.25	98.9	2.82	279	
5	Sept. 14....	"	1984	3.02	36.6	2.80	102	New Rod.
6	" 21....	"	Floats	7.30	260.8	2.97	774	
7	Oct. 8....	H. C. Hurd	"	3.35	53.7	2.25	122	
8	" 9....	"	"	3.65	69.0	2.71	187	
9	" 14....	"	"	4.85	132.7	3.07	408	
10	" 17....	"	"	4.25	105.1	2.86	300	
11	Nov. 23....	"	B. & B. 1	3.14	39.0	4.21	162	Velocity taken at 0.6 depth.
12	" 27....	"	1	3.03	36.5	3.72	136	" " " "
13	Dec. 13....	"	1	2.75	36.2	3.20	114	" " " "

RATING TABLE FOR RIO TOLA 100 FEET ABOVE ITS MOUTH.
This table is applicable only from June 9, 1898, to September 1, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
1.0	10	1.9	46	2.8	130	3.7	220	4.6	310
1.1	11	2.0	53	2.9	140	3.8	230	4.7	320
1.2	12	2.1	61	3.0	150	3.9	240	4.8	330
1.3	13	2.2	70	3.1	160	4.0	250	4.9	340
1.4	16	2.3	80	3.2	170	4.1	260	5.0	350
1.5	20	2.4	90	3.3	180	4.2	270	5.1	360
1.6	26	2.5	100	3.4	190	4.3	280	...	...
1.7	33	2.6	110	3.5	200	4.4	290	...	...
1.8	39	2.7	120	3.6	210	4.5	300	...	...

RATING TABLE FOR RIO TOLA ¾ MILE ABOVE ITS MOUTH.

This table is applicable only from September 1, 1898, to November 1, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
2.0	18	3.1	91	4.2	252	5.3	428	6.4	608
2.1	20	3.2	103	4.3	268	5.4	444	6.5	625
2.2	24	3.3	116	4.4	284	5.5	460	6.6	642
2.3	29	3.4	130	4.5	300	5.6	476	6.7	659
2.4	34	3.5	145	4.6	316	5.7	492	6.8	676
2.5	40	3.6	160	4.7	332	5.8	508	6.9	693
2.6	46	3.7	175	4.8	348	5.9	524	7.0	710
2.7	53	3.8	190	4.9	364	6.0	540	7.1	728
2.8	61	3.9	205	5.0	380	6.1	557	7.2	746
2.9	70	4.0	220	5.1	396	6.2	574	7.3	764
3.0	80	4.1	236	5.2	412	6.3	591	...	...

RATING TABLE FOR RIO TOLA ¾ MILE ABOVE ITS MOUTH.

This table is applicable only from November 1, 1898, to December 31, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
2.6	65	3.0	108	3.4	168	3.8	228
2.7	73	3.1	123	3.5	183	3.9	244
2.8	83	3.2	138	3.6	198	4.0	260
2.9	95	3.3	153	3.7	213	4.1	276

ESTIMATED MONTHLY DISCHARGE OF RIO TOLA ¾ MILE ABOVE ITS MOUTH.

Month. 1898.	Discharge in Second-Feet.			Total in Acre-Feet.	Month. 1898.	Discharge in Second-Feet.			Total in Acre-Feet.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
June (9-30)	355	12	53	2,310				Brought forward,	13,640
July	163	21	46	2,830	October	452	130	246	15,125
August	57	20	30	1,840	November	270	100	160	9,520
September.....	364	39	112	6,660	December	100	65	79	4,860
				13,640	Total				43,145

Lake Nicaragua.

Lake Nicaragua has an area of 2975 square miles. Its greatest length is from north-northwest, to south-southeast, and is about 100 miles. Its extreme width is about 45 miles.

West of the center is an island occupied by the volcanoes Ometepe and Madera, which stand about 5000 feet above the lake level, adding greatly to the scenic beauty.

Madera is the most southern of a line of volcanoes of comparatively recent origin, which extends in a northwesterly direction nearly to the bay of Fonseca, including Ometepe, Zapatero, Mombacho, Chiltepe, Momotombo, and many others.

The prevailing easterly trade winds cause a moderately heavy surf to beat almost constantly on the western shore, causing the formation of

a decided beach on that side, while on the eastern shore aquatic vegetation grows far out into the water. This shore is flat and muddy, with no well-marked beach.

Except in the southeastern portion the lake is deep, reaching in one point near the southern foot of Madera to a depth of 200 feet.

Lake Nicaragua receives the waters of a large number of tributaries, the most important being Rio Frio and Rio Pisote on the southern end, which rise in the high mountains of Costa Rica and maintain their flow throughout the dry season, and Malacatolla and Tipitapa on the northern end. The latter brings the waters of Lake Managua, which lies to the northwest of Lake Nicaragua and has an area of about 500 square miles. The drainage area as estimated from the best information obtainable, is as follows:

	Sq. miles.
Area of land surface draining directly to Lake Nicaragua	6,640
Area of Lake Nicaragua	2,975
Lake Managua and tributary basin	3,035
Total	12,450

The control of the waters of Lake Nicaragua is vital to the practical operation of the proposed ship canal and has an important bearing upon the cost and the plans of any project proposed. Careful observations of its fluctuations, of the maximum and minimum inflow and outflow, and of evaporation from its surface are therefore very important.

Las Lajas.

A station was established on the margin of Lake Nicaragua, about seven miles southeast of Rivas, and about 3500 feet north of the mouth of Las Lajas, on January 19. The gage was placed in a long box with open ends and seams, which was fastened to the sunken wreck of a large boiler of one of the Vanderbilt steamers, as shown in the figure. The box and the boiler served to protect the gage from the violence of the breakers prevalent on this coast, but afforded entirely free access to the water. The gage as first placed was insecurely fastened, and during a storm the waves beat it down. It was replaced on February 7 by Mr. J. A. Bull in the position which it now occupies. The gage is inclined to the vertical to such an extent that one foot vertical corresponds to 1.014 foot on the rod. The 10-foot mark is .65 feet below bench mark No. 1, which is the highest point of a large cylinder nearly buried in the sand on shore. The 10-foot mark is 108.04 feet above sea level by the levels of the Nicaragua Canal Commission.

The ebb and flow of the waves kept the water level constantly changing on the rod, and the readings were taken by averaging high and low readings occurring within a few seconds. Most of the time the eastern trades blew constantly, with considerable force, but during May were many calm days, and some adverse winds.

During April the declining lake surface threatened to leave the gage on dry land, and another gage was placed in deeper water, about 200 feet north of the first one. This was placed vertical and fastened to another portion of the wreck. On this gage the 9-foot mark is 103.19 feet above sea level. It was observed from May 1 to July 16, when the surf became too deep for the observer to safely read it, and observations were transferred to gage No. 1.

Temperature, humidity and wind observations were taken at this station, and at the mouth of Las Lajas an evaporation pan and rain gage were maintained and observed.

The elevation of Lake Nicaragua is given under the head of Fort San Carlos, page 211.

LOCATION OF LAKE GAGE, LAS LAJAS.

Rio Viejo.

This station is about 500 yards above the ford known as Paso Real on the Rio Viejo where the Matagalpa-Leon road crosses the Rio Viejo. A gage was placed at this point on February 1, which consisted of a vertical unpainted cedar stick, marked with nails and notches to feet and tenths, nailed to a tree on the right bank. A bench mark was established on the right bank consisting of a wire nail driven in the highest point of a stump 66 feet west of the gage. It is 46.2 feet above zero of gage. A cable was stretched across the river a short distance above the gage from which measurements of floods were made by means of a gaging car of the usual pattern. Measurements at low water were made by wading.

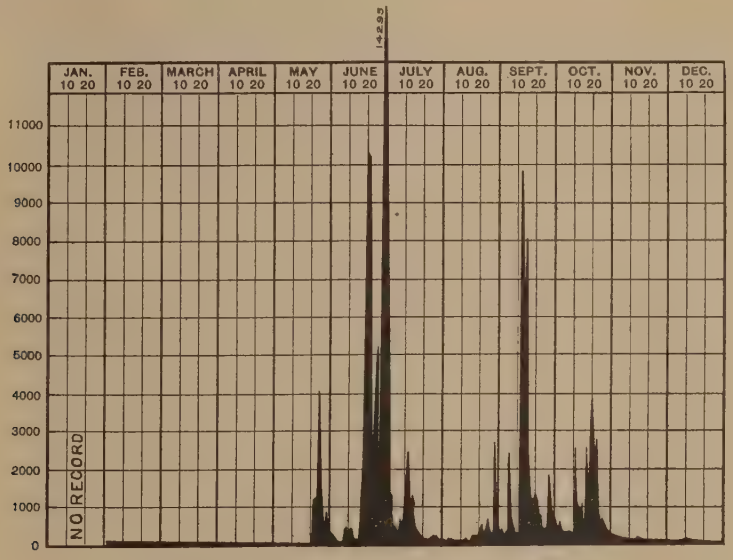


Fig. 2. Diagram of Daily Discharge of Rio Viejo, 1898.

DAILY GAGE HEIGHT OF RIO VIEJO AT PASO REAL FOR 1898.

Day.	Feb. 1898.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.
1	....	1.98	1.84	1.71	3.75	7.01	3.57	4.20	5.20	3.96	2.75	2.41
2	2.37	1.97	....	1.71	3.25	6.86	3.45	3.95	4.65	3.85	2.74	2.40
3	2.34	1.95	....	1.71	2 95	5.97	3.54	3.78	5.35	3.73	2.72	2.41
4	2.32	1.99	....	1.71	2.75	5.45	3.41	4.35	4.48	3.65	2.71	2.42
5	2.30	1.99	1.81	1.71	2.61	5.17	3.51	9.00	4.21	3.61	2.70	2.45
6	2.28	1.98	1.81	1.71	2.55	4.91	....	5.85	4.02	3.52	2.68	2.97
7	2.25	2.18	1.80	1.70	2.74	5.12	....	5.10	3.88	3.41	2.75	2.84
8	2.20	2.12	1.80	1.70	4.03	5.68	....	4.50	3.97	3.33	2.78	2.72
9	2.19	2.09	....	1.70	4.45	....	....	....	4.95	3.28	2.95	2.69
10	2.18	2.09	....	1.70	4.01	....	....	....	4.84	3.25	2.94	2.62
11	2.17	2.05	1.78	1.70	4.44	....	3.20	....	8.94	3.19	2.89	2.59
12	2.15	....	1.77	1.70	3.56	8.69	....	....	6.40	3.20	2.78	2.56
13	2.14	....	1.76	1.70	3.15	6.70	....	....	6.32	3.42	2.74	2.52

DAILY GAGE HEIGHT OF RIO VIEJO AT PASO REAL FOR 1898.—Continued.

Day	Feb. 1898.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.
14	2.13	1.98	1.74	1.70	2.93	6.84	3.20	14.50	6.30	3.59	2.71	2.50
15	2.11	1.97	1.74	1.70	2.75	5.90	3.80	17.50	6.37	3.27	2.69	2.49
16	....	1.95	1.74	1.70	2.65	5.35	....	9.50	5.31	3.13	2.66	2.49
17	....	1.93	1.74	1.70	2.62	4.77	....	7.75	6.45	3.07	2.62	2.48
18	2.08	1.93	1.73	1.79	8.11	4.46	....	6.35	9.00	3.00	2.60	2.48
19	2.08	1.92	1.73	1.84	9.90	4.17	....	6.53	7.33	3.00	2.59	2.45
20	2.06	1.92	1.72	1.80	20.70	3.97	....	6.80	10.89	2.98	2.58	2.44
21	2.02	1.91	1.73	1.96	12.50	3.82	....	6.60	8.44	2.95	2.56	2.43
22	2.01	1.90	1.72	2.81	10.34	3.70	....	5.95	9.07	2.95	2.56	2.35
23	2.05	1.88	1.72	6.55	8.63	3.65	....	5.81	7.04	2.91	2.56	....
24	2.02	1.87	1.72	6.60	12.85	3.65	5.60	5.20	5.90	2.90	2.56	....
25	2.01	1.85	1.72	11.94	9.90	3.42	4.38	4.75	5.43	2.87	2.54	....
26	....	1.88	1.71	6.78	7.35	3.38	3.93	5.10	5.70	2.84	2.51	....
27	....	1.87	1.71	5.71	6.40	3.38	3.76	7.85	5.37	2.84	2.48	....
28	....	1.85	1.71	5.15	27.00	3.50	3.65	6.25	4.90	2.82	2.48	....
29	....	1.83	1.71	5.59	11.41	3.78	9.23	5.21	4.75	2.84	2.45	....
30	....	1.85	1.71	4.31	8.03	3.71	5.55	6.08	4.42	2.80	2.44	....
31	....	1.83	....	4.14	....	3.62	3 90	....	4.16	....	2.42	....

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO VIEJO AT PASO REAL.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second-feet).
Feb. 8	F. C. Green	7	2.20	17.7	1.60	28.3
" 18	"	7	2.08	14.1	1.40	20.7
" 28	"	7	1.99	12.8	1.20	15.3
Mar. 8	"	7	2.12	14.0	1.57	22.0
" 18	"	7	1.94	11.4	1.23	14.0
" 28	"	7	1.85	10.8	0.55	6.0
April 8	"	7	1.79	9.6	0.44	4.3
" 20	G. P. Philip	7	1.72	6.2	0.61	3.8
" 28	"	7	1.71	5.4	0.58	3.2
May 6	"	7	1.71	7.2	0.37	3.5
" 14	"	7	1.70	6.8	0.32	2.2
" 22	"	7	3.12	62.4	3.30	206
" 25	"	7	12.52	964.0	5.06	4874
June 1	"	7	3.65	74	4.29	317
" 8	"	7	3.63	68	4.04	274
" 15	"	7	2.78	32	3.54	114
" 22	"	7	11.62	895	4.85	4344
" 29	"	7	12.34	976	4.65	4539
July 6	"	7	4.95	157	2.91	456
" 13	"	7	6.50	315	3.08	1072
" 20	"	7	3.97	83	3.21	266
" 27	"	7	3.38	55	2.78	152
Aug. 3	"	7	3.59	66	2.92	192
Sep. 19	"	7	5.72	188	4.40	828
" 27	"	7	8.23	460	4.52	2,074
Oct. 3	Fred. Davis	7	5.02	144	3.26	469
" 10	"	7	5.00	184	4.41	813
" 18	"	7	9.90	674	4.89	3,300

GAGING THE RIO VIEJO.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO VIEJO AT PASO REAL.—Continued.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second-feet).
Oct. 25	Fred. Davis	7	5.41	216	4.11	886
Nov. 1	"	7	4.00	81	3.48	282
" 7	"	7	3.42	54	3.42	182
" 14	"	7	3.52	72	2.16	228
" 21	"	7	2.95	34	2.73	94
" 28	"	7	2.82	35	2.36	82
Dec. 5	"	7	2.70	27.5	2.74	75
" 10	"	7	2.94	45	1.95	88
" 15	"	7	2.68	33.5	1.76	59
" 22	"	7	2.56	28.5	1.71	49
" 29	"	7	2.45	25	1.59	39
1899.						
Jan. 3	"	7	2.40	25.6	1.23	31.5
" 9	"	7	2.68	34.7	1.77	61.3
" 15	"	7	2.49	25.7	1.74	44.9

RATING TABLE FOR RIO VIEJO AT CROSSING OF MATAGALPA-LEON ROAD.
This table is applicable only from May 21, 1898, to December 1, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.
1.5	0	4.6	384	7.7	1,760	10.8	3,765	13.9	5,780
1.6	1	4.7	406	7.8	1,820	10.9	3,830	14.0	5,845
1.7	3	4.8	428	7.9	1,880	11.0	3,895	14.1	5,910
1.8	6	4.9	452	8.0	1,945	11.1	3,960	14.2	5,975
1.9	10	5.0	475	8.1	2,010	11.2	4,025	14.3	6,040
2.0	15	5.1	500	8.2	2,075	11.3	4,090	14.4	6,105
2.1	21	5.2	525	8.3	2,140	11.4	4,155	14.5	6,170
2.2	28	5.3	555	8.4	2,205	11.5	4,220	14.6	6,235
2.3	36	5.4	585	8.5	2,270	11.6	4,285	14.7	6,300
2.4	44	5.5	620	8.6	2,335	11.7	4,350	14.8	6,365
2.5	52	5.6	655	8.7	2,400	11.8	4,415	14.9	6,430
2.6	60	5.7	695	8.8	2,465	11.9	4,480	15.0	6,495
2.7	68	5.8	735	8.9	2,530	12.0	4,545	15.1	6,510
2.8	77	5.9	780	9.0	2,595	12.1	4,610	15.2	6,625
2.9	86	6.0	830	9.1	2,660	12.2	4,675	15.3	6,690
3.0	98	6.1	880	9.2	2,725	12.3	4,740	15.4	6,755
3.1	112	6.2	930	9.3	2,790	12.4	4,805	15.5	6,820
3.2	126	6.3	980	9.4	2,855	12.5	4,870	15.6	6,885
3.3	140	6.4	1,030	9.5	2,920	12.6	4,935	15.7	6,950
3.4	156	6.5	1,080	9.6	2,985	12.7	5,000	15.8	7,015
3.5	172	6.6	1,130	9.7	3,050	12.8	5,065	15.9	7,080
3.6	188	6.7	1,180	9.8	3,115	12.9	5,130	16.0	7,145
3.7	206	6.8	1,235	9.9	3,180	13.0	5,195	16.1	7,210
3.8	224	6.9	1,290	10.0	3,245	13.1	5,260	16.2	7,275
3.9	242	7.0	1,345	10.1	3,310	13.2	5,325	16.3	7,340
4.0	262	7.1	1,400	10.2	3,375	13.3	5,390	16.4	7,405
4.1	282	7.2	1,460	10.3	3,440	13.4	5,455	16.5	7,470
4.2	302	7.3	1,520	10.4	3,505	13.5	5,520	16.6	7,535
4.3	322	7.4	1,580	10.5	3,570	13.6	5,585	16.7	7,600
4.4	342	7.5	1,640	10.6	3,635	13.7	5,650	16.8	7,665
4.5	363	7.6	1,700	10.7	3,700	13.8	5,715	16.9	7,730

RATING TABLE FOR RIO VIEJO AT CROSSING OF MATAGALPA-LEON ROAD.

This table is applicable only from December 1, 1898, to January 22, 1899.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.
1.9	10	2.2	26	2.5	45	2.8	74	3.1	112
2.0	15	2.3	32	2.6	53	2.9	86	3.2	126
2.1	20	2.4	38	2.7	63	3.0	98	3.3	140

ESTIMATED MONTHLY DISCHARGE OF RIO VIEJO AT CROSSING OF MATAGALPA-LEON ROAD.

Month.	Discharge in Second-Feet.			Total in Acre-Feet.	Month.	Discharge in Second-Feet.			Total in Acre-Feet.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
1898.					1898.				Brought forward, 209,356
February	35	15	24	1,332	September	9,745	220	1,765	105,025
March	25	5	13	800	October	3,830	230	965	59,340
April	5	3	3.6	214	November	253	74	130	7,735
May	5,520	2	324	19,920	December	92	39	59	3,630
June	15,600	50	2,170	129,120	1899.			Total for 1898	385,086
July	2,400	155	613	37,680	January	94	35	49	3,013
August	2,750	125	330	20,290	Total				388,099
				209,356					

Rio Nueva.

This station was established February 1, at the bend of Rio Nueva, where it approaches nearest Rio Viejo, in the neighborhood of Paso Real, and was intended to throw light on the quantity of water that might be added to the supply for Lake Managua by diverting this river into it.

Measurements were made by wading at low water and by means of floats at high water. The stage of the river was ascertained by measuring downward with a tape-line from a nail driven in an overhanging trunk of a tree. These measurements were carried on by the same observer who had charge of the station at Rio Viejo.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO NUEVA NEAR RIO VIEJO.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge (second-feet.).	Remarks.
May 23	G. P. Philip	Floats.	5.0	178	2.54	451	
" 27	"	"	4.3	126	2.18	275	
June 3	"	7	3.0	50	0.70	35.4	
" 10	"	Floats.	3.42	71	1.32	95.6	
" 17	"	7	3.02	57	0.69	39.5	
" 24	"	Floats.	18.10	490	4.81	2361	New Gage-Rod.
July 1	"	"	14.80	230	3.01	693	
" 8	"	"	14.70	223	2.79	622	
" 15	"	"	14.30	193	2.29	441	
" 22	"	"	13.0	105	1.37	143	

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO NUEVA NEAR RIO VIEJO.—Continued.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge (second-feet).	Remarks.
July 29	G. P. Philip	Floats.	13.4	132	2.14	282	
" 29	"	7	13.4	133	2.03	269	
Aug. 26	"	Floats.	12.5	74	1.86	138	
Sept. 17	"	"	15.0	248	2.84	704	Approximation.
" 28	"	"	15.8	303	2.71	821	
Oct. 3	Fred. Davis	"	14.1	181	2.35	425	
" 14	"	"	15.2	265	2.83	750	
" 22	"	"	16.4	350	3.93	1,376	
" 31	"	"	14.1	181	2.84	514	
Nov. 6	"	"	13.3	124	2.76	343	
" 12	"	"	13.5	76	2.47	187	
" 19	"	"	12.80	31	2.22	65.5	
" 24	"	"	12.70	30	1.97	60	
" 28	"	"	12.70	30	2.17	66	
Dec. 4	"	7	12.60	48	1.06	51	
" 8	"	7	12.50	45	0.99	45	
" 15	"	7	12.30	42.5	1.16	49	
" 21	"	7	12.21	36.	0.77	28	
" 30	"	7	12.15	34.6	0.60	20.7	
1899.							
Jan. 2	"	7	12.21	38.8	0.78	30.3	
" 9	"	7	12.30	40.3	1.01	40.7	
" 15	"	7	12.19	36.2	0.71	25.8	

RATING TABLE FOR RIO NUEVA NEAR RIO VIEJO.

This table is applicable only from June 24, 1898, to January 22, 1899.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.
12.3	80	13.5	300	14.7	590	15.9	1,080	17.1	1,660
12.4	90	13 6	320	14.8	625	16.0	1,125	17.2	1,720
12.5	105	13.7	340	14.9	660	16.1	1,170	17.3	1,780
12.6	120	13.8	360	15.0	700	16.2	1,215	17.4	1,850
12.7	140	13.9	380	15.1	740	16.3	1,260	17.5	1,920
12.8	160	14.0	400	15.2	780	16.4	1,305	17.6	1,990
12.9	180	14.1	425	15.3	820	16.5	1,350	17.7	2,060
13.0	200	14.2	450	15.4	860	16.6	1,400	17.8	2,130
13.1	220	14.3	475	15.5	900	16.7	1,450	17.9	2,200
13.2	240	14.4	500	15.6	945	16.8	1,500	18.0	2,280
13.3	260	14.5	530	15.7	990	16.9	1,550	....	.....
13.4	280	14.6	560	15.8	1,035	17.0	1,600	....	.....

River dry from February 13 to May 20.

Quebrada Honda.

This stream is tributary to Rio Viejo about two miles below the station on the latter. A gage was placed one-half mile above the wagon ford on the road from Leon to Matagalpa and graduated to feet and tenths. At low water, measurements were made by wading; at high water, by means of floats.

LIST OF DISCHARGE MEASUREMENTS MADE ON QUEBRADA HONDA ABOVE CROSSING OF MATAGALPA-LEON ROAD.

Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge. (second-feet).
May 27	J. G. Philips	Floats.	5.10	112	1.59	178
June 3	"	7	4.10	69	0.27	19
" 10	"	Floats.	4.88	104	1.65	171
" 17	"	7	4.22	79	0.32	25
" 25	"	Floats.	9.10	276	4.35	1,200
July 1	"	"	5.28	109	1.82	198
" 29	"	7	4.22	74	0.48	35
Aug. 26	"	Floats.	4.60	88	1.64	145
Sept. 28	"	"	5.68	129	2.18	281
Oct. 4	Fred. Davis	"	4.68	89	1.61	144
" 11	"	"	4.75	93	1.89	176
" 23	"	"	7.05	184	3.23	593
" 30	"	"	4.62	89	1.72	153
Nov. 6	"	"	4.30	76	1.01	76
" 12	"	"	4.21	73	0.71	52
" 19	"	"	4.05	68	0.43	29
" 24	"	"	4.00	65	0.37	24.5
" 28	"	"	3.98	65	0.36	23.5
Dec. 4	"	7	3.90	8.5	1.12	9.5
" 9	"	7	3.90	7.5	0.80	6.0
" 16	"	7	3.85	7.5	0.84	6.3
" 22	"	7	3.80	6.2	0.59	3.7
" 28	"	7	3.80	3.9	0.48	1.9

Tipitapa.

A gage was placed in this river about 100 yards above Tipitapa falls, which serves both to register the stage of the river and the height of Lake Managua upon which the stage of the river depends. During low water the river was too sluggish above the falls for accurate measurements with current meter, and gagings were made from the bridge below the falls. As the river rose it became very turbulent and swift at the bridge, but at the same time the velocity in the upper river increased and good measurements were made above the falls. Observations of rainfall and evaporation were also made at this point.

Lake Managua lies to the northwest of Lake Nicaragua and drains into the latter through Rio Tipitapa. Its area is about 438 square miles.

Reports of the discharge of Tipitapa river are conflicting. All agree that the stream goes dry in the latter part of every dry season. Some authorities assert that it has been dry for several years in succession, the inflow during the rainy season being insufficient to compensate for evaporation, while others maintain that there is more or less outflow every year in the rainy season. Investigations were therefore made to determine roughly the feasibility of diverting the Rio Nueva which now drains into the Rio Grande, into Rio Viejo and finally into Lake Managua. Near the station on Rio Viejo the two rivers approach within about a mile of each other and the intervening country is low and flat. The river channels are 30 to 40 feet deep and a cut

GAGING STATION AT TIPITAPA, OUTLET OF LAKE MANAGUA, JUST BELOW FALLS.

ESTIMATED MONTHLY DISCHARGE OF TRIBUTARIES TO SAN JUAN RIVER BETWEEN SABALOS AND SAN CARLOS RIVERS.

This is the difference between the discharge of the San Juan above Boca San Carlos and at Sabalos.

Drainage area 750 square miles, approximately.

Month.	Discharge in Second-feet.			Total in Acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per sq. mile.
1898.						
January (10–31)	5,100	900	2,630	114,770	2.87	3.51
February	17,600	2,700	5,450	302,680	7.57	7.27
March	6,600	1,300	2,820	173,400	4.34	3.76
April	12,700	1,100	2,960	176,130	4.40	3.95
May	7,000	500	2,380	146,340	3.66	3.17
June	21,000	1,000	8,270	492,100	12.31	11.03
July	21,600	7,800	13,350	820,860	20.52	17.80
August	16,100	3,400	6,580	404,590	10.11	8.77
September	15,900	2,600	7,140	424,860	10.62	9.52
October	11,900	2,000	6,050	373,000	9.30	8.07
November	45,000	2,800	11,080	659,360	16.47	14.76
December	15,600	2,900	6,540	402,150	10.05	8.72
Total 1898				4,490,240		
1899.						
January	14,400	4,300	8,330	512,190	12.80	11.10
February	7,100	3,200	4,390	243,810	6.09	5.85
March	4,400	2,800	3,590	220,750	5.53	4.80

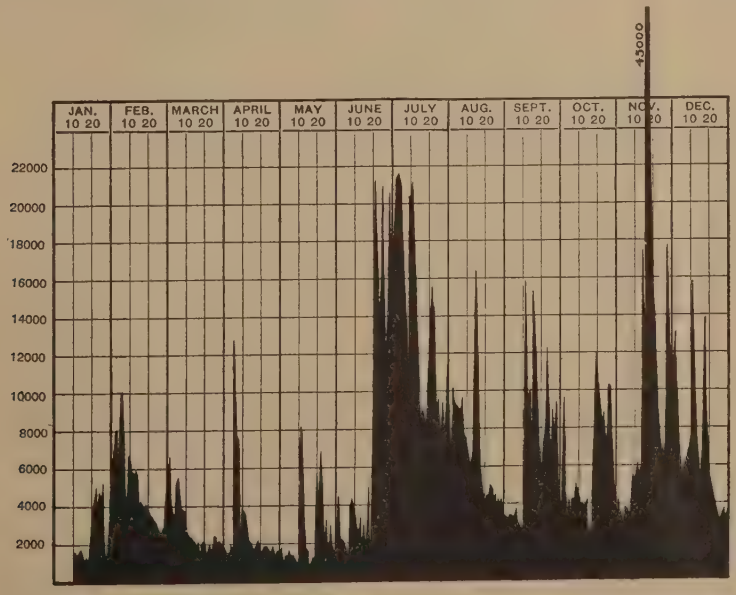


FIG. 4. Diagram of daily discharge of tributaries of San Juan between Sabalos and Boca San Carlos, 1898.

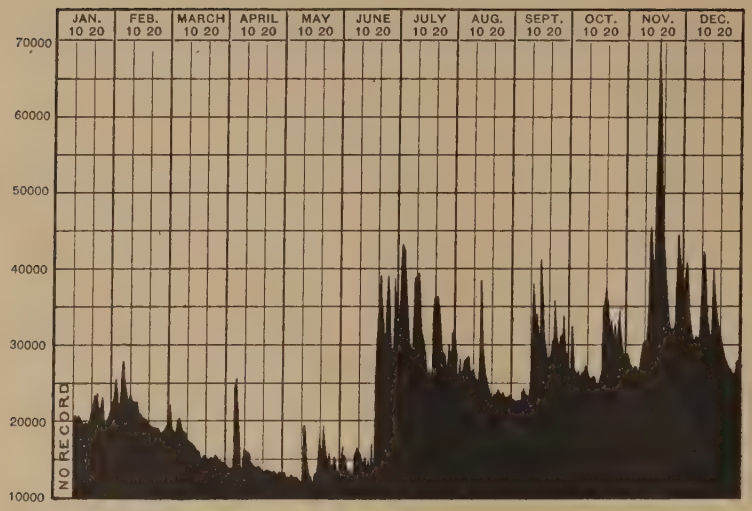


FIG. 5. Diagram of daily discharge of the San Juan above Boca San Carlos.

RIO SAN CARLOS.

The San Carlos river is a wide, swift stream, heading in the high mountains of Costa Rica. From these mountains it obtains large quantities of volcanic sand, portions of which become ground fine enough to be held in suspension, and large quantities are carried both in this way and rolled on the bottom of the stream, especially in times of great floods to which this river is subject. Its drainage area as measured from the best maps obtainable is 1450 square miles, but this must be regarded as merely a rough approximation, as the country has never been even thoroughly explored, much less accurately mapped. Above the mouth of the San Carlos the San Juan is a stream of comparatively uniform discharge, the greater portion of its water coming from Lake Nicaragua, which acts as a very effective regulator upon the floods in the basin. From the mouth of San Carlos river to the foot of Machuca rapids the San Juan is very deep and the current consequently sluggish. This portion is called the Aguas Muertas, or dead waters. It frequently occurs that the San Carlos is in flood, and the large volume of water affects the water surface of the Aguas Muertas, in proof of which a rise in the San Juan below Machuca rapids has been observed, amounting to nearly four feet at a time when the San Carlos was in flood, while no rise whatever occurred above the rapids. The large quantity of material carried by the San Carlos river has built a delta at its mouth so that it flows to the San Juan through two channels around a deltaic island, and from its mouth to the sea the bottom of the San Juan is covered with moving sands brought in by the San Carlos.

Station on Rio San Carlos.—A station was established on the San Carlos river about three miles above its mouth, on the 10th day of January, 1898. The gage consists of a pine board painted white and graduated to feet and tenths from zero to 15 feet, the reading being continued on another board fastened to another tree

a short distance downstream and higher up on the bank. A §-inch steel cable was placed across the river at this point, upon which traveled a gaging car from which measurements were made.

In times of high water the stream is so swift that it is difficult to make the meter sink to the desired point in the stream, the tendency of the meter, in spite of heavy lead weights, being to drift downstream and rise to the surface, under the joint influence of the current and the suspending wire. To overcome this difficulty another and smaller cable was thrown across the river about 200 feet above the main cable, which carried a small pulley block. To this pulley a cord was fastened, and the other end attached to the meter cord just above the meter. This held the instrument from drifting downstream, and a heavy lead sinker would carry it to any desired depth, where it could be held without difficulty. This arrangement is illustrated in Plate VIII. A sediment trap was also employed at this station, suspended from the cable when in operation.

PLATE VII. Starting to gage a river.

A bench mark was made by driving a spike into a large root of the tree used as a cable support, which stood out from the tree like an abutment. The bench mark is 30.74 feet above zero of the gage. The high water occurring

from the 2d to the 8th of January scoured out the channel of the river somewhat, so that a separate rating table has been made for January and another for the months, February, March, April and May; still another, somewhat different, is used from the 1st of June for the balance of the season.

DAILY GAGE HEIGHT OF SAN CARLOS RIVER THREE MILES ABOVE ITS MOUTH FOR 1898-9.

1898.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	1899. Jan.	Feb.	Mar.
Day.															
1....	....	12.79	12.35	11.47	11.03	12.88	15.30	13.01	13.00	13.00	14.20	13.85	11.90	11.85	12.40
2....	....	16.21	12.83	11.45	11.19	12.30	15.93	13.80	13.16	13.15	13.80	13.65	12.75	11.85	12.20
3....	....	16.06	12.58	11.45	11.03	11.88	15.31	14.90	12.90	12.80	13.50	14.05	14.35	11.80	12.15
4....	....	17.41	12.37	11.43	11.05	11.68	14.92	14.05	13.05	12.75	13.90	13.75	12.80	11.70	12.05
5....	....	19.23	13.32	12.93	11.05	11.58	16.10	14.87	13.15	12.75	13.45	13.65	12.60	11.65	12.00
6....	....	18.26	13.43	13.15	11.08	11.50	14.97	14.74	13.15	13.95	13.35	13.95	12.40	11.60	11.85
7....	....	16.20	12.73	13.29	11.03	12.25	15.18	13.94	12.85	13.25	14.00	13.50	12.15	12.05	11.85
8....	....	15.92	12.43	13.00	11.01	11.98	16.78	13.58	12.60	13.10	14.90	13.30	12.55	12.00	12.70
9....	....	15.20	12.33	13.00	11.00	11.75	18.11	13.30	12.45	13.35	16.65	13.10	12.50	11.70	12.80
10....	16.00	14.60	12.43	12.35	11.01	12.30	19.53	13.14	12.48	13.30	16.50	13.70	12.35	11.70	12.20
11....	15.40	14.27	12.40	12.00	11.02	12.28	17.13	13.40	13.10	13.30	15.35	16.75	12.20	11.70	11.95
12....	15.00	13.95	12.22	12.05	11.04	11.95	15.68	13.52	12.55	13.80	14.85	15.05	12.35	11.70	11.80
13....	14.62	13.76	12.08	11.98	11.04	11.85	15.25	14.65	14.25	13.60	19.10	14.35	13.00	12.70	11.75
14....	14.35	13.47	11.97	11.86	11.12	12.97	14.85	15.51	14.50	13.75	18.05	13.95	13.25	14.70	11.80
15....	14.07	13.39	11.87	11.71	11.13	12.60	14.45	14.38	13.75	13.30	16.70	13.55	12.90	13.45	11.70
16....	14.07	13.15	11.95	11.60	11.64	13.19	14.59	14.09	14.50	14.15	16.55	13.35	15.00	13.25	11.65
17....	14.25	12.95	11.95	11.46	11.76	13.49	14.20	13 65	14.40	13.75	20.20	13.30	13.60	12.70	11.55
18....	13.87	12.80	12.53	11.48	11.88	13.11	14.10	13.42	13.85	16.40	17.60	13.15	13.25	12.85	11.50
19....	13.65	12.85	11.89	11.60	12.05	13.78	14.13	13.23	13.75	16.90	16.40	12.90	13.20	12.95	11.50
20....	13.47	12.71	11.74	11.51	13.50	14.38	14.25	13.45	14.90	16.10	15.50	12.75	13.20	12.85	11.40
21....	13.65	12.61	11.69	11.41	12.55	14.29	14.12	13.50	13.95	14.90	15.05	12.60	12.85	13.30	11.40
22....	13.47	12.54	11.66	11.29	12.54	13.74	13.81	14.58	14.30	14.35	14.70	12.50	12.65	12.85	11.30
23....	13.27	12.52	11.65	11.40	12.18	13.90	13.69	13.86	15.00	14.30	14.30	12.40	12.55	13.70	11.25
24....	13.05	12.36	11.56	11.48	12.09	15.98	13.33	13.93	13.80	16.30	14.00	12.20	12.50	13.20	11.20
25....	12.88	12.45	11.68	11.41	11.93	15.20	13.21	13.70	13.70	15.15	13.90	12.20	12.60	12.90	11.15
26....	12.77	12.45	12.19	11.31	11.74	15.15	13.12	13.60	13.50	19.30	13.85	12.20	12.35	12.55	11.10
27....	12.81	13.05	12.69	11.34	11.55	17.70	12.98	13.90	14.05	16.15	13.65	12.20	12.20	12.80	11.10
28....	13.68	13.00	12.44	11.33	11.90	18.53	12.84	13.80	13.95	15.25	13.90	12.10	12.15	12.60	11.05
29....	13.17	....	11.98	11.13	12.00	16.92	14.14	13.35	13.50	14.85	14.00	12.00	12.05	....	11.10
30....	13.02	....	11.74	11.05	11 85	15.53	13.50	13.00	13.30	14.40	14.65	11.95	12.00	....	11.10
31....	12.80	....	11.63	....	12.60	....	13.08	13.10	....	15.05	....	11.95	11.90	....	11.05

LIST OF DISCHARGE MEASUREMENTS MADE ON SAN CARLOS RIVER THREE MILES ABOVE ITS MOUTH.

Date.	Hydrographer.	Meter number.	Gage height (ft).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge (sec.-ft.).	Remarks.
1898.							
Jan. 27.....	R. Breese.....	65	12.63	2,897	3.26	9,445	
" 29.....	"	65	13.17	3,529	3.57	12,602	
" 31.....	"	65	12.75	3,076	3.37	10,352	
Feb. 2.....	"	65	16.37	5,509	4.00	22,208	Rising.
" 4.....	"	65	17.87	6,503	4.27	27,782	Rising rapidly.
" 5.....	"	65	19.00	....	....	.....	Battery failed.
" 10.....	"	65	14.59	4,380	4.59	14,890	
" 11.....	"	65	14.19	3,642	3.34	12,201	

LIST OF DISCHARGE MEASUREMENTS MADE ON SAN CARLOS RIVER THREE MILES ABOVE ITS MOUTH.—Continued.

Date.	Hydrographer.	Meter number.	Gage height (ft.).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge (sec.-ft.).	Remarks.
1898.							
Mar. 12	R. Breese	65	12.22	2,372	2.88	6,834	
April 6	"	65	13.10	3,092	3.01	9,331	
" 21	"	65	11.40	1,800	2.85	5,130	
May 13	R. C. Wheeler	65	11.03	1,615	2.56	4,139	
" 14	"	65	11.18	1,736	2.61	4,526	
" 17	"	65	11.58	1,990	2.61	5,187	
" 20	"	65	13.69	3,557	3.12	11,096	
June 20	H. S. Reed	65	14.39	3,846	3.42	13,156	
" 22	"	65	13.72	3,360	3.18	10,672	
" 24	"	65	16.73	5,503	3.71	20,414	
" 27	"	65	18.55	7,227	4.08	29,480	
" 29	"	65	17.26	6,001	3.67	22,009	
" 30	"	65	15.57	4,787	3.50	16,762	
July 4	"	65	14.85	4,303	2.97	12,800	
" 6	"	65	15.05	4,469	3.24	14,464	
" 10	"	65	20.33	8,929	4.31	38,506	
" 13	"	65	15.43	4,761	3.31	15,763	
" 22	"	65	13.88	3,520	3.04	10,700	
" 26	"	65	13.20	3,036	2.88	8,746	
" 30	"	65	13.53	3,310	2.94	9,844	
Aug. 2	"	65	12.94	2,820	2.94	8,296	
" 3	"	65	15.70	4,873	3.50	17,074	
" 5	"	65	15.20	4,499	3.30	14,824	
" 5	"	65	15.27	4,544	3.33	15,112	
" 14	"	65	15.93	5,114	3.27	16,730	
" 22	"	65	14.56	3,952	3.17	12,434	
" 28	"	65	13.89	3,579	3.01	10,781	
Sept. 8	"	65	12.60	2,781	2.83	7,857	
" 10	"	65	12.48	2,830	2.75	7,791	
" 14	"	65	14.47	4,039	3.08	12,436	
" 22	"	65	14.32	3,940	3.21	12,652	
Oct. 4	"	65	12.77	2,600	3.11	8,185	
" 18	"	65	16.69	5,472	3.79	20,714	
" 20	"	65	16.07	5,190	3.52	18,275	
Nov. 14	"	65	18.10	6,880	3.78	26,030	
" 17	"	65	20.11	8,579	3.76	32,265	
" 19	"	65	16.42	5,766	3.32	19,120	
" 28	"	65	13.90	3,576	2.96	10,570	
Dec. 15	"	65	13.55	3,428	3.03	10,385	
" 19	"	65	12.90	2,875	2.92	8,504	
" 21	"	65	12.60	2,592	2.91	7,543	
" 27	"	65	12.20	2,260	2.85	6,431	
" 31	"	65	11.94	2,195	2.51	5,505	
1899.							
Jan. 2	Chas. Hayman	65	12.75	2,812	2.72	7,657	
" 3	"	65	14.23	3,819	3.03	11,564	
" 13	"	65	13.06	3,084	2.77	8,555	
" 16	"	65	14.98	4,415	3.23	14,266	
" 31	"	65	11.90	2,105	2.56	5,380	
Feb. 3	"	65	11.78	1,991	2.52	5,016	
" 13	"	65	13.13	2,869	3.00	8,608	
" 14	"	65	14.66	3,980	3.23	12,862	
" 20	"	65	12.90	2,987	2.69	8,031	
Mar. 1	"	65	12.38	2,660	2.53	6,733	
" 9	"	65	12.76	2,947	2.62	7,725	
" 17	"	65	11.53	2,193	2.39	5,245	
" 20	"	65	11.40	1,887	2.60	4,897	
" 24	"	65	11.20	1,917	2.52	4,836	
" 29	"	65	11.10	1,782	2.48	4,414	

RATING TABLE FOR SAN CARLOS RIVER, AT CAMP, THREE MILES ABOVE MOUTH.

Table good for January, 1898, only.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
12.5	9,000	13.4	13,960	14.3	18,820	15.2	23,680
12.6	9,540	13.5	14,500	14.4	19,360	15.3	24,220
12.7	10,180	13.6	15,040	14.5	19,900	15.4	24,760
12.8	10,720	13.7	15,580	14.6	20,440	15.5	25,300
12.9	11,260	13.8	16,120	14.7	20,980	15.6	25,840
13.0	11,800	13.9	16,660	14.8	21,520	15.7	26,380
13.1	12,340	14.0	17,200	14.9	22,060	15.8	26,920
13.2	12,880	14.1	17,740	15.0	22,600	15.9	27,560
13.3	13,420	14.2	18,280	15.1	23,140	16.0	28,000

RATING TABLE FOR SAN CARLOS RIVER, AT CAMP, THREE MILES ABOVE MOUTH.

This table is applicable only from February 1, 1898, to May 30, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
11.0	4,100	12.8	8,500	14.6	14,900	16.4	21,900
11.1	4,340	12.9	8,750	14.7	15,280	16.5	22,300
11.2	4,580	13.0	9,000	14.8	15,660	16.6	22,700
11.3	4,820	13.1	9,360	14.9	16,040	16.7	23,100
11.4	5,040	13.2	9,720	15.0	16,420	16.8	23,500
11.5	5,280	13.3	10,080	15.1	16,800	16.9	23,900
11.6	5,520	13.4	10,440	15.2	17,180	17.0	24,300
11.7	5,760	13.5	10,800	15.3	17,560	17.1	24,700
11.8	6,000	13.6	11,160	15.4	17,940	17.2	25,100
11.9	6,250	13.7	11,520	15.5	18,320	17.3	25,500
12.0	6,500	13.8	11,880	15.6	18,700	17.4	25,900
12.1	6,750	13.9	12,240	15.7	19,100	17.5	26,300
12.2	7,000	14.0	12,620	15.8	19,500	17.6	26,700
12.3	7,250	14.1	13,000	15.9	19,900	17.7	27,100
12.4	7,500	14.2	13,380	16.0	20,300	17.8	27,500
12.5	7,750	14.3	13,760	16.1	20,700	17.9	27,900
12.6	8,000	14.4	14,140	16.2	21,100	18.0	28,300
12.7	8,250	14.5	14,520	16.3	21,500	....	.....

RATING TABLE FOR SAN CARLOS RIVER, AT CAMP, THREE MILES ABOVE MOUTH.

This table is applicable only from June 1, 1898, to November 30, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
11.0	4,100	11.8	5,910	12.6	7,800	13.4	9,800
11.1	4,320	11.9	6,140	12.7	8,050	13.5	10,050
11.2	4,540	12.0	6,370	12.8	8,300	13.6	10,300
11.3	4,760	12.1	6,600	12.9	8,550	13.7	10,560
11.4	4,980	12.2	6,830	13.0	8,800	13.8	10,830
11.5	5,200	12.3	7,060	13.1	9,050	13.9	11,100
11.6	5,430	12.4	7,300	13.2	9,300	14.0	11,380
11.7	5,680	12.5	7,550	13.3	9,550	14.1	11,660

RATING TABLE FOR SAN CARLOS RIVER, AT CAMP, THREE MILES ABOVE MOUTH.—Continued.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
14.2	11,940	16.0	17,340	17.8	25,000	19.6	34,100
14.3	12,220	16.1	17,680	17.9	25,500	19.7	34,700
14.4	12,500	16.2	18,020	18.0	26,000	19.8	35,300
14.5	12,780	16.3	18,360	18.1	26,500	19.9	35,900
14.6	13,060	16.4	18,700	18.2	27,000	20.0	36,500
14.7	13,340	16.5	19,050	18.3	27,500	20.1	37,100
14.8	13,620	16.6	19,400	18.4	28,000	20.2	37,700
14.9	13,900	16.7	19,750	18.5	28,500	20.3	38,300
15.0	14,200	16.8	20,100	18.6	29,000	20.4	38,900
15.1	14,500	16.9	20,500	18.7	29,500	20.5	39,500
15.2	14,800	17.0	21,000	18.8	30,000	20.6	40,100
15.3	15,100	17.1	21,500	18.9	30,500	20.7	40,700
15.4	15,400	17.2	22,000	19.0	31,000	20.8	41,300
15.5	15,700	17.3	22,500	19.1	31,500	20.9	41,900
15.6	16,000	17.4	23,000	19.2	32,000	21.0	42,500
15.7	16,330	17.5	23,500	19.3	32,500	....	.....
15.8	16,660	17.6	24,000	19.4	33,000	....	.....
15.9	17,000	17.7	24,500	19.5	33,500	....	.....

RATING TABLE FOR SAN CARLOS RIVER, THREE MILES ABOVE ITS MOUTH.

This table is applicable only from December 1, 1898, to March 31, 1899.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
11.0	4,230	13.1	8,860	15.2	14,800	17.3	22,500
11.1	4,380	13.2	9,140	15.3	15,100	17.4	23,000
11.2	4,530	13.3	9,420	15.4	15,400	17.5	23,500
11.3	4,680	13.4	9,700	15.5	15,700	17.6	24,000
11.4	4,830	13.5	9,980	15.6	16,000	17.7	24,500
11.5	4,980	13.6	10,260	15.7	16,330	17.8	25,000
11.6	5,140	13.7	10,540	15.8	16,660	17.9	25,500
11.7	5,320	13.8	10,820	15.9	17,000	18.0	26,000
11.8	5,520	13.9	11,100	16.0	17,340	18.1	26,500
11.9	5,740	14.0	11,380	16.1	17,680	18.2	27,000
12.0	5,980	14.1	11,660	16.2	18,020	18.3	27,500
12.1	6,240	14.2	11,940	16.3	18,360	18.4	28,000
12.2	6,500	14.3	12,220	16.4	18,700	18.5	28,500
12.3	6,760	14.4	12,500	16.5	19,050	18.6	29,000
12.4	7,020	14.5	12,780	16.6	19,400	18.7	29,500
12.5	7,280	14.6	13,060	16.7	19,750	18.8	30,000
12.6	7,540	14.7	13,340	16.8	20,100	18.9	30,500
12.7	7,800	14.8	13,620	16.9	20,500	19.0	31,000
12.8	8,060	14.9	13,900	17.0	21,000	....	.....
12.9	8,320	15.0	14,200	17.1	21,500	....	.....
13.0	8,580	15.1	14,500	17.2	22,000	....	.....

ESTIMATED MONTHLY DISCHARGE OF SAN CARLOS RIVER THREE MILES ABOVE ITS MOUTH.

Drainage area, 1,450 square miles, approximately.

Month.	Discharge in Second-feet.			Total in Acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per sq. mile.
1898.						
January (10–31)	28,000	10,560	16,055	700,582	9.09	11.1
February	34,300	7,400	13,530	751,380	9.68	9.3
March	11,341	5,140	7,030	432,260	5.53	4.8
April	10,080	4,220	6,038	359,285	4.69	4.2
May	11,880	4,100	5,560	341,870	4.38	3.8
June	32,250	5,200	10,720	637,880	8.26	7.4
July	41,600	8,400	14,094	866,605	11.18	9.7
August	15,730	8,800	10,990	675,750	8.76	7.6
September	14,200	7,420	10,319	614,023	7.92	7.1
October	32,500	8,180	12,880	791,960	10.26	8.9
November	32,260	9,680	15,440	918,750	11.88	10.6
December	19,920	5,850	9,290	571,220	7.38	6.4
Total, 1898				7,661,565		
1899.						
January	14,200	5,720	7,865	483,600	6.23	5.4
February	13,340	4,940	7,360	408,750	5.31	5.1
March	8,060	4,300	5,400	332,030	4.27	3.7

Ochoa Station on the San Juan.

One of the most important as well as most disputed points regarding hydrographic knowledge in Nicaragua is the discharge of the Rio San Juan at Ochoa, where it is proposed to build a high dam. A station was established here on December 30, 1897. A vertical pine gage was fastened to an overhanging tree on the right bank, and was graduated to feet and tenths, to 15 feet, and continued upward on another plank fastened to the same tree.

A standard copper bench mark of the U. S. Geological Survey was established on the right bank near the tree which bears the gage. It is a copper plate placed horizontally on top of a stump, with its stem driven into an auger hole in the stump. It is 28.10 feet above the zero of the gage. The channel at this point is straight, and the bottom is reasonably permanent.

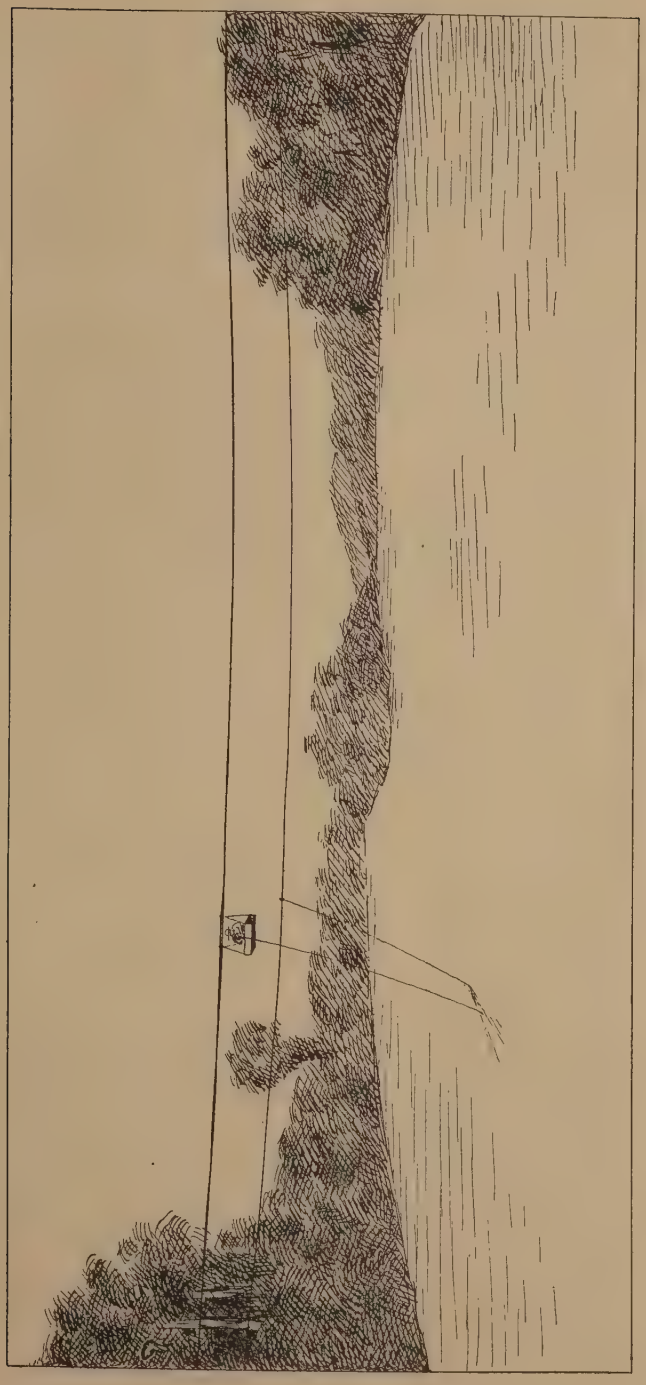


PLATE VIII. Gaging the San Carlos River.

DAILY GAGE HEIGHT OF SAN JUAN RIVER AT OCHOA FOR 1898-9.

1898.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	1899. Jan.	Feb.	Mar.
Day.															
1....	14.80	7.83	7.50	5.38	4.75	6.65	11.30	8.63	7.93	8.55	9.55	10.90	8.60	7.60	7.22
2....	14.45	9.45	7.20	5.30	4.55	6.15	12.38	8.90	7.98	9.75	9.18	11.20	9.32	7.58	7.12
3....	15.83	10.48	7.00	5.28	4.55	5.60	12.75	9.38	7.88	8.63	9.00	10.60	9.85	7.47	7.02
4....	15.60	9.30	6.85	5.40	4.53	5.43	12.40	9.13	7.93	8.45	9.05	10.20	9.30	7.38	6.92
5....	13.38	12.70	7.60	8.10	4.63	5.30	12.35	9.53	8.00	8.55	8.95	9.85	9.55	7.30	6.88
6....	13.55	12.45	7.73	8.58	4.58	5.20	11.08	9.75	8.20	8.93	8.90	9.75	9.28	7.30	6.78
7....	14.70	10.63	7.18	7.65	4.55	5.48	10.43	9.40	8.13	8.75	9.10	9.75	8.92	7.50	6.78
8....	12.30	9.78	6.90	7.35	4.50	6.03	11.13	9.25	7.90	8.73	9.78	9.60	9.07	7.45	7.28
9....	11.23	9.40	6.83	7.10	4.40	6.05	12.95	8.75	7.80	9.00	10.98	9.48	8.92	7.30	7.40
10....	10.95	9.13	6.75	6.35	4.33	6.28	13.85	8.78	7.78	8.85	10.88	10.43	9.07	7.25	6.98
11....	10.40	8.78	6.73	6.10	6.40	6.08	12.48	8.63	10.68	8.68	10.43	12.60	8.97	7.25	6.75
12....	9.98	8.55	6.53	6.08	6.18	5.73	11.08	8.65	9.65	8.85	10.23	11.10	9.85	7.45	6.65
13....	9.63	8.43	6.43	5.95	4.95	5.90	10.53	9.30	10.53	8.78	13.08	10.38	10.37	8.38	6.60
14....	9.33	8.10	6.33	5.70	4.65	6.13	10.10	11.65	10.45	8.88	13.68	9.90	9.90	8.98	6.55
15....	8.95	7.83	6.18	5.50	4.63	6.23	9.58	10.45	9.65	8.58	12.30	9.53	9.97	8.15	6.52
16....	8.90	7.68	6.08	5.35	4.70	6.28	9.28	9.65	11.65	8.80	13.28	9.38	10.55	7.98	6.48
17....	9.15	7.50	6.08	5.25	4.93	7.08	9.15	8.98	10.73	8.88	17.20	11.05	9.95	7.90	6.35
18....	....	7.38	6.18	5.28	5.25	6.38	9.05	8.53	9.88	11.30	15.03	10.15	9.42	8.25	6.30
19....	....	7.40	5.95	5.35	5.40	9.45	10.15	8.25	9.53	11.95	13.15	9.35	9.17	8.20	6.28
20....	....	7.28	5.83	5.15	7.33	10.53	10.88	8.20	9.70	11.83	12.18	9.03	9.02	8.00	6.25
21....	....	7.18	5.70	5.10	6.53	11.45	10.85	8.28	9.60	10.85	11.48	8.78	8.75	8.22	6.22
22....	....	7.10	5.75	5.05	7.08	10.28	10.38	8.85	9.95	10.25	10.90	8.60	8.52	7.80	6.12
23....	8.80	7.05	5.70	5.10	6.15	9.75	9.65	8.60	11.05	10.38	10.48	8.53	8.45	8.10	6.02
24 ...	8.35	6.90	5.65	5.13	5.85	11.55	9.10	8.60	9.75	11.03	10.10	8 33	8.35	7.90	6.00
25....	8.13	6.90	5.93	5.00	5.78	11.98	9.05	8.40	9.45	10.75	10.00	8.25	8.35	7.70	5.98
26....	8.10	6.93	6.15	4.98	5.63	10.90	8.85	8.40	9.65	12.70	10.23	8.18	8.15	7.42	5.90
27....	8.30	7.28	6.38	5.00	5.50	12.00	8.63	8.40	9.93	11.40	10.70	8.15	8.02	7.50	5.82
28....	8.53	7.43	6.20	4.85	5.93	12.75	9.18	8.40	10.43	10.58	11.85	8.13	7.97	7.40	5.80
29....	8.30	....	5.88	4.78	5.75	12.95	9.45	8.18	9.30	10.15	11.68	8.30	7.82	....	5.80
30....	8.10	....	5.65	4.70	5.50	11.18	9.70	8.10	8.90	9.75	10.95	8.25	7.72	....	5.78
31....	8.03	....	5.53	....	6.28	....	9.68	7.98	....	9.83	....	8.30	7.65	....	5.70

For purposes of current meter measurements it was not permissible to extend a cable over the river at this point on account of navigation. It was first intended to make measurements by means of a boat anchored to a small cable stretched across the river, which should carry tags indicating distances from the initial point, and which when not in use was to be held against the bottom of the river by means of sinkers. Experience on this line, however, soon demonstrated that it would be difficult, if not impracticable, to maintain a small cable in the position proposed on account of the large quantities of driftwood, leaves and brush passing down the river, especially in times of flood, when the gaging apparatus would be most in demand. Another project was therefore inaugurated, which was the anchorage of a number of buoys at known distances from the initial point, said buoys to be constructed of "balsa," a very light, bulky endogenous wood much used in the construction of rafts, etc. This method of marking distances from the initial point was successfully employed for several months during the season of low water, but as the rains increased and freshets began to come down the river the great quantity of leaves and brush carried by the water attached themselves to the buoys and their

anchorages until they were either carried beneath the surface of the river or washed away entirely. The method permanently adopted required the employment of an additional instrument man to manipulate a telescope on shore and measure the distance of the boat during the process of gaging, by means of a stadia rod.

LIST OF DISCHARGE MEASUREMENTS MADE ON SAN JUAN RIVER AT OCHOA.

Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (ft. per sec'd).	Discharge (second-ft.)	Remarks.
Jan. 8.....	G. R. Wadleigh.....	1985	11.94	13,100	4.00	52,400	
" 12.....	"	1985	9.87	11,940	3.67	43,830	
" 27.....	"	1985	8.30	9,906	3.33	33,050	
Feb. 8.....	"	1985	9.78	10,916	3.75	40,913	
" 16.....	"	1985	7.65	8,966	3.29	29,458	
" 28.....	"	1985	7.40	8,602	3.21	27,600	
Mar. 10.....	"	1985	6.73	8,132	3.07	24,974	
" 19.....	"	1985	5.95	7,703	2.89	22,270	
Apr. 1.....	"	1985	5.35	7,225	2.91	21,017	
" 14.....	"	1985	5.73	7,359	3.03	22,327	
" 27.....	"	1985	4.99	6,728	2.72	18,290	
May 10.....	"	1985	4.30	5,654	2.86	16,145	
Jun. 4.....	"	1985	5.41	6,637	3.08	20,461	
" 17.....	"	1985	6.64	7,794	3.34	26,066	
" 23.....	"	1985	9.68	10,922	3.88	42,350	
" 26.....	A. P. Davis.....	1894	11.13	11,994	3.88	46,529	Falling.
" 28.....	G. R. Wadleigh.....	1985	12.91	14,462	4.25	61,410	"
July 8.....	"	1985	11.52	13,418	3.86	51,821	Rising.
" 11.....	"	1985	12.42	14,438	3.80	55,089	
" 16.....	"	1985	9.12	11,211	3.32	37,213	
" 19.....	"	1985	10.53	12,586	3.66	46,098	
" 25.....	"	1985	8.96	9,782	3.78	36,940	
" 28.....	"	1985	9.56	10,506	3.97	39,832	
Aug. 1.....	"	1985	8.68	9,826	3.56	35,980	
" 3.....	"	1985	10.21	11,094	3.84	42,640	
" 7.....	"	1985	9.42	10,359	3.63	37,647	
Sep. 3.....	H. S. Reed.....	65	7.85	8,938	3.68	32,984	
" 12.....	"	65	9.38	10,336	4.00	41,199	
" 16.....	"	65	12.02	12,761	4.47	57,047	
" 26.....	"	65	9.43	9,895	4.24	41,975	
Oct. 1.....	"	65	8.52	8,815	3.97	34,971	
" 17.....	"	65	8.88	9,026	4.44	40,087	
" 18.....	"	65	11.79	12,076	4.85	58,620	
Nov. 8.....	"	65	9.77	10,800	4.40	47,472	
" 13.....	"	65	14.05	14,171	5.59	79,210	
" 17.....	"	65	17.43	19,717	5.32	104,930	
" 19.....	"	65	13.00	14,734	4.53	66,800	
" 30.....	"	65	10.89	12,057	4.39	52,950	
Dec. 12.....	"	65	11.02	12,069	4.23	51,042	
" 19.....	"	65	9.28	10,872	3.89	41,904	
" 22.....	"	65	8.60	10,286	3 88	39,859	
" 28.....	"	65	8.10	9,565	3.71	35,452	
" 30.....	"	65	8.25	9,767	3.80	37,089	
1899.							
Jan. 6.....	"	65	9.20	10,626	3.90	41,404	
" 13.....	"	65	10.21	12,006	4.04	48,530	
" 21.....	"	65	8.75	10,257	3.74	38,346	
" 26.....	"	65	8.12	9,779	3.55	34,688	
" 30.....	"	65	7.71	9,176	3.59	32,976	
Feb. 7.....	"	65	7.52	9,113	3.52	32,115	
" 21.....	"	65	8.13	9,775	3.67	35,852	
" 25.....	"	65	7.63	9,393	3.56	33,416	
" 28.....	"	65	7.37	8,972	3.49	31,314	
Mar. 3.....	"	65	7.01	8,863	3.41	30,184	
" 7.....	"	65	6.80	8,954	3.30	29,553	
" 13.....	"	65	6.60	8,372	3.35	28,048	
" 31.....	"	65	5.70	7,589	3.08	23,369	

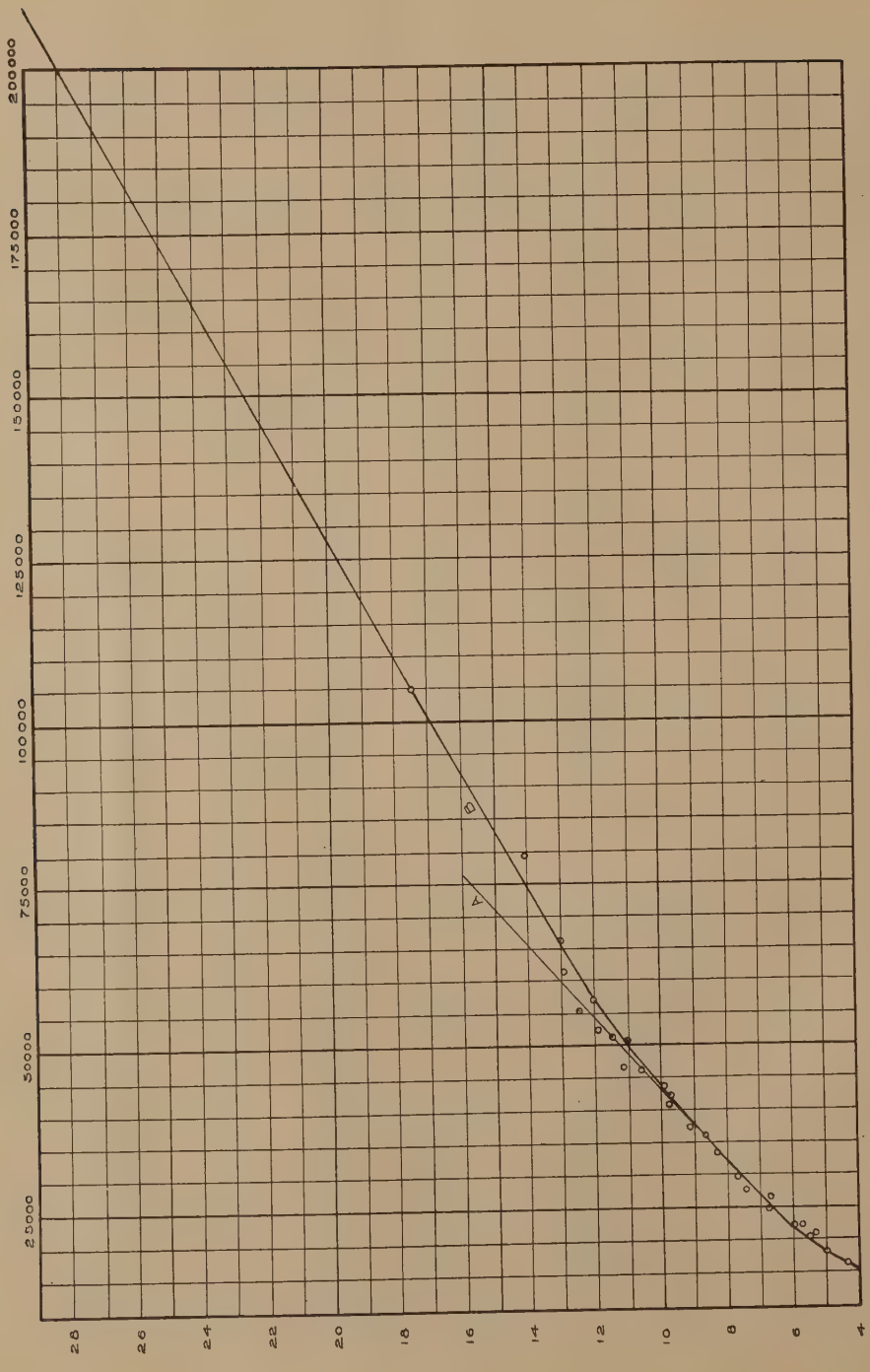


PLATE IX. Rating curves for San Juan River at Ochoa. A—applicable from Jan. 1 to July 9. B—from July 9 to Dec. 31, 1898.

The highest measurement of discharge yet made at this point was on November 17, at a gage height of 17.43 feet, when the river was discharging 104,928 cubic feet per second. At this stage the river was about 8.5 feet below the flood-plain at Ochoa, the formation of which indicates that it is sometimes overflowed.

Dr. C. W. Hayes, geologist of the expedition, expresses the opinion that this flood-plain is at intervals of ten to thirty years covered by the floods of San Juan river to a depth of more than six inches, but less than three feet. In other words, maximum gage readings of 26.5 to 29 may be expected with moderate frequency at Ochoa station. The considerations on which this conclusion is based are outlined below:

Physical Characteristics of the San Juan Flood-plain.—The San Juan river from the mouth of the San Carlos eastward flows in a valley which has recently been depressed below sea level. This old valley since submergence has been filled with sediment contributed chiefly by the San Carlos and Sarapiqui, but in some measure also by the smaller tributaries. The San Juan may at one time have flowed into an estuary which has filled from its head seaward, and after the estuary had been filled a delta was pushed beyond into the open sea. The alluvial plain thus formed had from the start a slope dependent upon the volume of the river and the quantity and character of the sediment which it carried. As the mouth of the river was pushed eastward its bed and its entire flood-plain were raised by the deposit of alluvium, the seaward slope always remaining the same, except as the volume of the river and its load may have varied. This process is still going on. As the length of the river increases by increments to its delta, its flood-plain is built up so as to preserve the long gradient.

Throughout this process of alluviation the elevation of the flood-plain above the river bed has remained practically the same, since this is dependent on the relative volumes of the river at extreme stages of high and low water and on the relative amount of fine and coarse sediment which it carried. It is important to note the entire absence of terraces on the San Juan. As river terraces are fossil flood-plains, marking a former higher flowage plain, their absence in a river basin may be regarded as good evidence that the river is not cutting down but building up its bed, and, at a corresponding rate, its flood-plain also.

The sediment carried by the river may be classed as silt and sand. The former consists of clay, vegetable matter and fine sand; the latter chiefly of rather coarse sand and fine gravel, with some pebbles up to an inch in diameter. The sand is transported chiefly by rolling along the bottom of the river bed and at all stages of water, although much more is carried at flood than at low water by reason of the higher velocity. By far the greater part of the sand is carried within a few inches of the river bed and very little ever reaches more than a few feet from the bottom. The silt, on the other hand, is carried by suspension in the body of the stream and varies in amount with its volume only because it is furnished more abundantly with flood waters and not because it cannot be carried by the slacker current at low water. The silt remains in suspension until quiet water is reached, and hence is either carried far out to sea or is deposited on the flood-plain when that is overflowed. Although the flood-plain has the same seaward slope as the river bed, or a slope slightly greater, it receives deposits of the finest silt when flooded. The requisite retardation of the current is effected chiefly by the dense growth of vegetation which everywhere covers it. This vegetation not only checks the current, but acts as a kind of filter by which the sediment is caught and held. Hence the deposit is more rapid on the immediate river bank and a natural levee is built up, back of which is a lower, swampy area. A subordinate reason for the more rapid deposition of silt on the river bank is that the water covering the swamps back from the river is largely derived from the rainfall in the immediate vicinity, hence free from silt, and only in part from the overflow of silt-laden waters from the river. This levee is generally from one to three feet higher than the depressed area, though the difference in elevation is naturally much greater in the case of a wide than a narrow flood-plain. It is manifest that the flood-plains are undergoing continuous degradation. This is favored by the unconsolidated character of the material and is retarded by the dense covering of vegetation and the low slopes. If the bed of the stream should remain for a considerable time at a constant elevation a condition of equilibrium would at length be reached between the forces tending to build up and those tending to degrade the flood-plains. As this condition was approached the floods of sufficient height to overflow the banks would become less frequent with the increased height of the banks, and the deposition of silt would be correspondingly slower. Further, it is only during the

comparatively rapid building of the flood-plain that conditions favor the formation of the natural levee. On the immediate bank of the river degradation is most rapid, chiefly by reason of the proximity to steep slopes and through the process of the flattening of slopes. The amount of sediment deposited by standing water varies directly as the depth of the water, hence a flood which barely overtops the levee may fill the depressed area behind with a considerable depth of water, and if the majority of the floods which are building the plain thus barely overtop the levee they will tend to bring the entire surface of the flood-plain to a level. The fact that the flood-plains are still growing, as proved by the absence of terraces and the existence of natural levees, may therefore be regarded as good evidence that the floods rise to a considerable height above its surface.

A secondary flood-plain is frequently observed. It is usually quite narrow and may occupy any position between the main flood-plain and the bars, which are uncovered only at the lowest stages. It is on such flood-plains that the most rapid deposition is taking place. They always occupy the concave side of the river, opposite which active cutting is going on. They serve to compensate for the lateral corrasion and preserve the normal river section. As their surface approaches that of the main flood-plain deposition becomes gradually slower until they merge with the broader plain.

From considerations given more fully elsewhere, it appears probable that the bed of the San Juan from the foot of the Machuca rapids to Lake Nicaragua, differs from that below Ochoa in that it is being lowered instead of raised. The lowering between the foot of the Machuca rapids and the head of the Toro rapids has probably been considerable, and a careful examination of this portion of the river valley should reveal remnants of former flood-plains in the shape of terraces. Above Sabalos the river has probably remained at a constant elevation for a long time and the flood-plains have perhaps reached nearly the point of equilibrium. Deposition of alluvium, however, is much slower here than farther down, since the water leaving the lake is practically clear and only a small amount of sediment is added to it by the few tributaries between the lake and Sabalos. Hence the surface of the flood-plains probably marks very nearly the stream height of water at the normal high floods.

The Relation of Floods to the Flood-plain.—The floods of all rivers may be conveniently classed in three categories: (1) normal annual floods; (2) normal high floods; (3) exceptional high floods. The normal annual floods of the San Juan do not reach the main flood-plain, at least in the vicinity of Ochoa. They probably fail to overtop the banks by at least three to five feet, covering only the secondary flood-plains mentioned above. On these they leave considerable deposits, the character of the material depending on their elevation. It varies from coarse sand on the bars just emerging above low water to fine silt where the secondary plain approaches the main flood-plain.

The normal high floods undoubtedly cover the flood-plains. While it is impossible to make exact statements either as to the frequency of the floods or the depth of the water on the flood-plain, there is some basis for a tolerably fair estimate. From the considerations given above it is certain that these high floods are of sufficient frequency and of sufficient height so that the depth of the alluvium which they deposit exceeds the surface degradation in the interval from one flood to another. The two factors favoring rapid deposition are abundance of sediment and the dense vegetation of the flood-plains. The latter also retards the degradation by projecting the unconsolidated material. With these favorable conditions for deposition we should expect to find the flood-plains built up nearly to the limit fixed by the extreme normal floods. That it has not reached the limit appears from the presence of the natural levees, for these, as shown above, would disappear when the point of equilibrium was reached. Moreover, frequent floods which barely overtopped the banks would tend to obliterate the inequalities. Hence the presence of these levees and other inequalities in the flood-plain would indicate that the floods were at rather long intervals, but that they covered the plain to a considerable depth. From these considerations it would seem probable that at intervals of ten to thirty years floods may be expected in the San Juan of sufficient height to cover the flood-plains in the vicinity of Ochoa to a depth of more than six inches, but less than three feet.

All large rivers are liable to exceptional high floods, due to a rare combination of circumstances, which take place at long intervals, probably measured by generations or centuries. Such floods are too variable in height and come at too great intervals to produce a flood-plain or other permanent record. They are liable to effect extensive changes in the course of the river and in its banks and in the vegetation growing on the flood-plains, but these effects are all of a temporary nature and are quickly obliterated. The exceptional nature of these floods, however, and the long intervals at which they are to be expected, remove them from among the agents which must be provided against in the construction of controlling works.

C. W. Hayes.

Plotting all observations of discharge, so far taken as abscissas, with corresponding gage heights as ordinates, we obtain a curve indicating the relation of gage height to discharge, showing that the ratio of increase of discharge to increase of gage height is not constant. The curve is concave downward, tending toward a horizontal position, showing that the increase of discharge for increase of gage height is greater at high stages than at low stages, but above a medium stage of the river the line curves but slightly, and though the concavity is still downward, the curve approaches a straight line, or in other words, the ratio between gage height and discharge approaches constancy. If we assume as constant the direction given to the line by the higher measurements, and continue it upward as a straight line, we obtain as the discharge corresponding to a gage height of 28 feet, about 200,000 cubic feet per second. (See Plate IX.)

If any curvature be given the extrapolated portion of the curve it will increase this amount.

If the same course of reasoning be applied to the flood-plain on the Rio San Carlos we find that its maximum discharge must be about 100,000 cubic feet per second.

Similarly it may be proved by extrapolating the curve discharge of the Rio San Juan at Fort San Carlos, that at the stage of 111 feet above sea level the lake must have discharged nearly 50,000 cubic feet per second.

When the measurement of November 17 that gave a discharge at Ochoa of 104,928 second-feet was made, the Rio San Carlos was discharging only 32,265, leaving 72,663 as the amount coming down the San Juan proper, of which probably not more than 28,663 were flowing from the lake, leaving 44,000 to be supplied by the small tributaries between the lake and Boca San Carlos. With such an indicated discharge, it would not be excessive to assume a maximum for these tributaries of 50,000 cubic feet per second, and we have the maximum flood at Ochoa made up as follows:

	Second-feet.
Maximum Rio San Carlos	100,000
Maximum discharge from lake	50,000
Maximum small tributaries	50,000
Maximum at Ochoa	200,000

The highest observed discharge of the Sarapiqui is 30,000 cubic feet per second. It is probable that the extreme maximum is not much less than 60,000 cubic feet per second. The Machado, San Francisco, Tamborcito and San Juanillo, and a large number of lesser creeks, contribute a large aggregate in time of flood, so that it is probable that at rare intervals the increment to the waters of the San Juan below Ochoa may amount to 100,000 cubic feet per second. Such an occurrence coincident with extreme flood conditions above Ochoa would make a total of 300,000 cubic feet per second discharging into the Caribbean through the various mouths of the San Juan.

RATING TABLE FOR SAN JUAN RIVER AT OCHOA.
This table is applicable only from January 1, 1898, to July 9, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
4.0	15,500	4.5	16,750	5.0	18,220	5.5	19,950
4.1	15,750	4.6	17,010	5.1	18,550	5.6	20,320
4.2	16,000	4.7	17,290	5.2	18,890	5.7	20,690
4.3	16,250	4.8	17,590	5.3	19,240	5.8	21,070
4.4	16,500	4.9	17,900	5.4	19,590	5.9	21,460

RATING TABLE FOR SAN JUAN RIVER AT OCHOA.—Continued.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
6.0	21,860	8.5	34,880	11.0	48,630	13.5	62,380
6.1	22,270	8.6	35,430	11.1	49,180	13.6	62,930
6.2	22,690	8.7	35,980	11.2	49,730	13.7	63,480
6.3	23,120	8.8	36,530	11.3	50,280	13.8	64,030
6.4	23,570	8.9	37,080	11.4	50,830	13.9	64,580
6.5	24,030	9.0	37,630	11.5	51,380	14.0	65,130
6.6	24,500	9.1	38,180	11.6	51,930	14.1	65,680
6.7	25,000	9.2	38,730	11.7	52,480	14.2	66,230
6.8	25,530	9.3	39,280	11.8	53,030	14.3	66,780
6.9	26,080	9.4	39,830	11.9	53,580	14.4	67,330
7.0	26,630	9.5	40,380	12.0	54,130	14.5	67,880
7.1	27,180	9.6	40,930	12.1	54,680	14.6	68,430
7.2	27,730	9.7	41,480	12.2	55,230	14.7	68,980
7.3	28,280	9.8	42,030	12.3	55,780	14.8	69,530
7.4	28,830	9.9	42,580	12.4	56,330	14.9	70,080
7.5	29,380	10.0	43,130	12.5	56,880	15.0	70,630
7.6	29,930	10.1	43,680	12.6	57,430	15.1	71,180
7.7	30,480	10.2	44,230	12.7	57,980	15.2	71,730
7.8	31,030	10.3	44,780	12.8	58,530	15.3	72,280
7.9	31,580	10.4	45,330	12.9	59,080	15.4	72,830
8.0	32,130	10.5	45,880	13.0	59,630	15.5	73,780
8.1	32,680	10.6	46,430	13.1	60,180	15.6	73,930
8.2	33,230	10.7	46,980	13.2	60,730	15.7	74,480
8.3	33,780	10.8	47,530	13.3	61,280		
8.4	34,330	10.9	48,080	13.4	61,830		

RATING TABLE FOR SAN JUAN RIVER AT OCHOA.

This table is applicable only from July 9, 1898, to December 31, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
4.0	15,500	7.6	29,930	11.2	50,500	14.8	81,200
4.1	15,750	7.7	30,480	11.3	51,300	14.9	82,100
4.2	16,000	7.8	31,030	11.4	52,100	15.0	83,000
4.3	16,250	7.9	31,580	11.5	52,900	15.1	83,900
4.4	16,500	8.0	32,130	11.6	53,700	15.2	84,800
4.5	16,750	8.1	32,680	11.7	54,500	15.3	85,700
4.6	17,010	8.2	33,230	11.8	55,300	15.4	86,600
4.7	17,290	8.3	33,780	11.9	56,150	15.5	87,500
4.8	17,590	8.4	34,330	12.0	57,000	15.6	88,400
4.9	17,900	8.5	34,880	12.1	57,850	15.7	89,300
5.0	18,220	8.6	35,430	12.2	58,700	15.8	90,200
5.1	18,550	8.7	35,980	12.3	59,550	15.9	91,100
5.2	18,890	8.8	36,530	12.4	60,400	16.0	92,000
5.3	19,240	8.9	37,080	12.5	61,250	16.1	92,900
5.4	19,590	9.0	37,630	12.6	62,100	16.2	93,800
5.5	19,950	9.1	38,180	12.7	62,950	16.3	94,700
5.6	20,320	9.2	38,730	12.8	63,800	16.4	95,600
5.7	20,690	9.3	39,280	12.9	64,650	16.5	96,500
5.8	21,070	9.4	39,830	13.0	65,500	16.6	97,400
5.9	21,460	9.5	40,380	13.1	66,350	16.7	98,300
6.0	21,860	9.6	40,930	13.2	67,200	16.8	99,200
6.1	22,270	9.7	41,480	13.3	68,050	16.9	100,100
6.2	22,690	9.8	42,030	13.4	68,900	17.0	101,000
6.3	23,120	8.9	42,580	13.5	69,750	17.1	101,900
6.4	23,570	10.0	43,130	13.6	70,600	17.2	102,800
6.5	24,030	10.1	43,680	13.7	71,450	17.3	103,700
6.6	24,500	10.2	44,230	13.8	72,300	17.4	104,600
6.7	25,000	10.3	44,780	13.9	73,150	17.5	105,500
6.8	25,530	10.4	45,330	14.0	74,000	17.6	106,400
6.9	26,080	10.5	45,880	14.1	74,900	17.7	107,300
7.0	26,630	10.6	46,480	14.2	75,800	17.8	108,200
7.1	27,180	10.7	47,100	14.3	76,700	17.9	109,100
7.2	27,730	10.8	47,750	14.4	77,600	18.0	110,000
7.3	28,280	10.9	48,400	14.5	78,500		
7.4	28,830	11.0	49,100	14.6	79,400		
7.5	29,380	11.1	49,800	14.7	80,300		

NICARAGUA CANAL COMMISSION

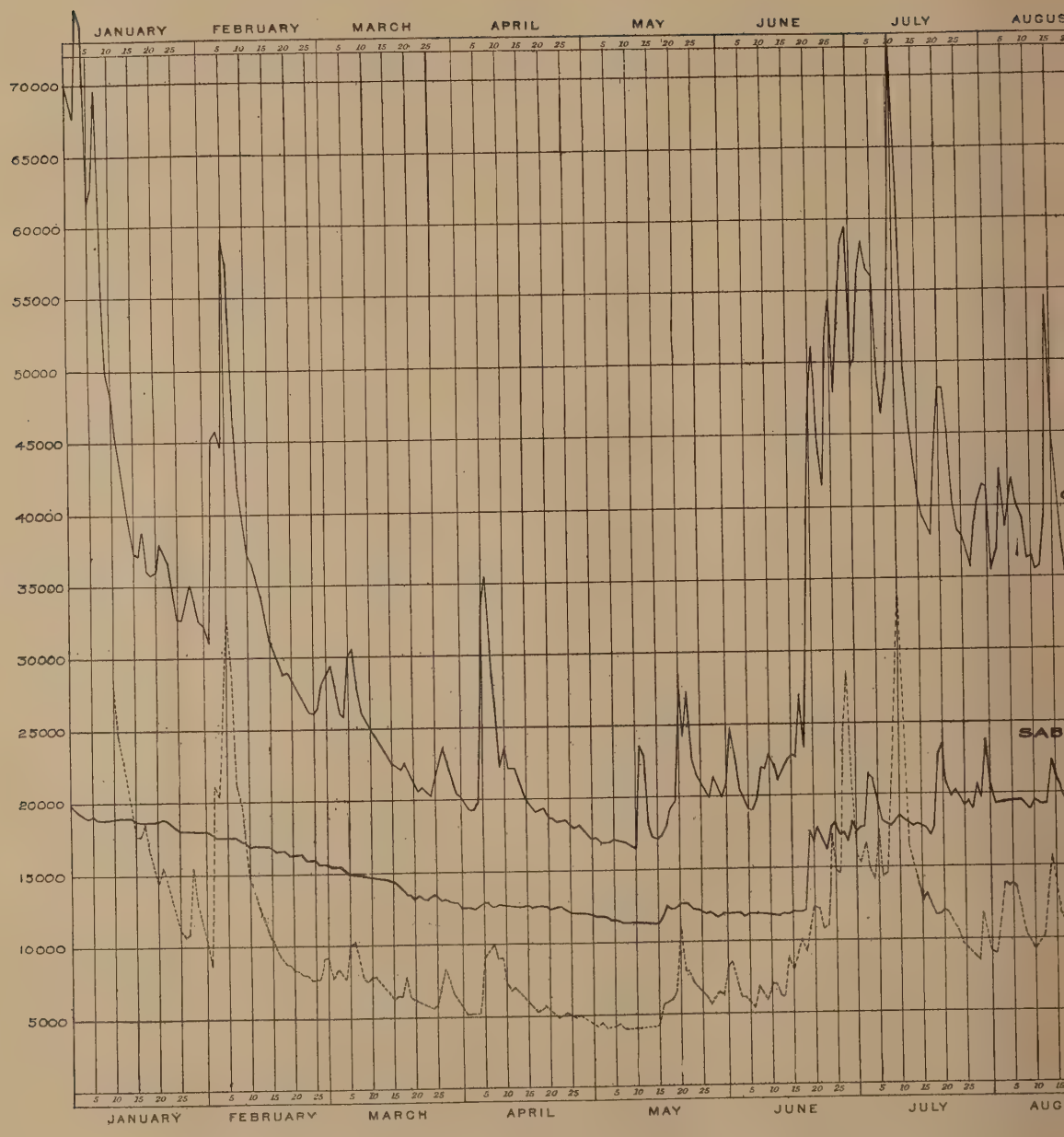
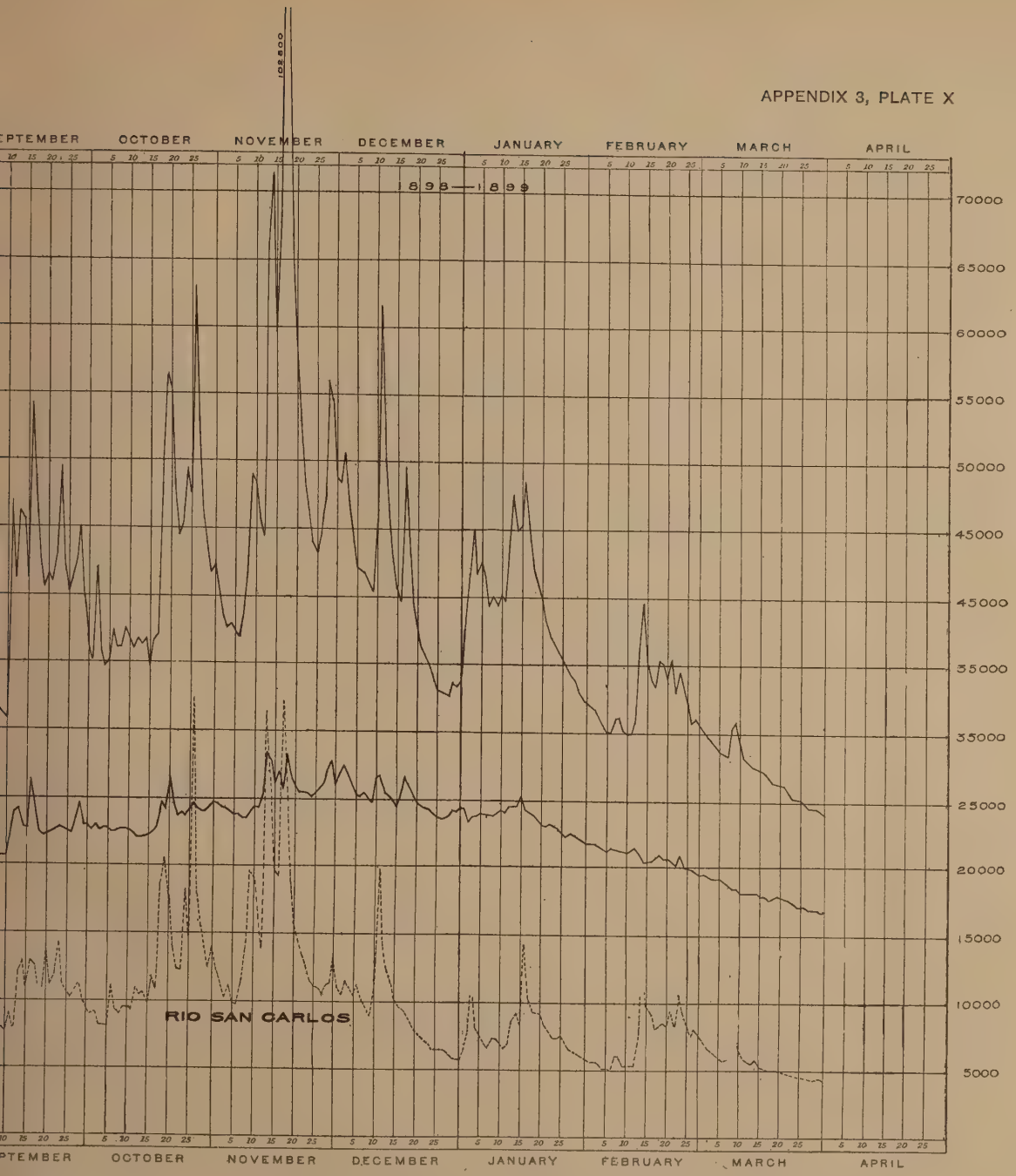


DIAGRAM OF THE DAILY MEAN DISCHARGE IN CUBIC FEET PER SECOND OF THE RIO SAN JUA



ALOS AND AT OCHOA; ALSO OF THE RIO SAN CARLOS AT 3 MILES ABOVE ITS MOUTH, 1898-1899.

RATING TABLE FOR SAN JUAN RIVER AT OCHOA.

This table is applicable only from January 1, 1899, to March 31, 1899.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
5.7	23,900	7.6	31,800	9.5	42,550	11.4	53,450
5.8	24,300	7.7	32,310	9.6	43,120	11.5	54,060
5.9	24,700	7.8	32 860	9.7	43,690	11.6	54,680
6.0	25,100	7.9	33,430	9.8	44,260	11.7	55,320
6.1	25,500	8.0	34,000	9.9	44,830	11.8	55,980
6.2	25,900	8.1	34,570	10.0	45,400	11.9	56,660
6.3	26,300	8.2	35,140	10.1	45,970	12.0	57,380
6.4	26,700	8.3	35,710	10.2	46,540	12.1	58,130
6.5	27,100	8.4	36,280	10.3	47,110	12.2	58,910
6.6	27,500	8.5	36,850	10.4	47,680	12.3	59,700
6.7	27,900	8.6	37,420	10.5	48,250	12.4	60,500
6.8	28,300	8.7	37,990	10.6	48,820	12.5	61,310
6.9	28,700	8.8	38,560	10.7	49,390	12.6	62,130
7.0	29,100	8.9	39,130	10.8	49,960	12.7	62,960
7.1	29,500	9.0	39,700	10.9	50,530	12.8	63,800
7.2	29,950	9.1	40,270	11.0	51,100	12.9	64,650
7.3	30,400	9.2	40,840	11.1	51,680	13.0	65,500
7.4	30,850	9.3	41,410	11.2	52,260		
7.5	31,300	9.4	41,980	11.3	52,850		

ESTIMATED MONTHLY DISCHARGE OF SAN JUAN RIVER AT OCHOA.

Month.	Discharge in Second-Feet.			Total for Month in Acre-Feet.
	Maximum.	Minimum.	Mean.	
1898.				
January	75,200	32,240	45,250	2,782,300
February	58,530	26,080	35,400	1,966,000
March	30,650	20,140	23,800	1,463,400
April	40,380	17,290	21,150	1,258,510
May	34,880	16,300	19,640	1,207,600
June	60,180	18,890	33,140	1,971,970
July	78,050	35,540	46,810	2,878,200
August	54,100	32,020	37,230	2,289,200
September	54,100	30,920	39,530	2,352,200
				18,169,380

Month.	Discharge in Second-Feet.			Total for Month in Acre-Feet.
	Maximum.	Minimum.	Mean.	
1898.	Brought forward,			18,169,380
October	67,625	34,600	42,200	2,594,800
November	107,000	37,080	51,890	3,087,670
December	65,000	32,790	40,850	2,511,770
Total for 1898				26,363,620
1899.				
January	49,100	32,000	39,665	2,438,900
February	41,120	29,840	32,540	1,807,180
March	31,300	23,900	26,940	1,656,480

Rio Machado.

The observer at Ochoa also made occasional measurements of the discharge of the Rio Machado, which are given below:

LIST OF DISCHARGE MEASUREMENTS.
Made on Rio Machado two miles above its mouth.

Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. feet).	Mean velocity (ft. per second).	Discharge (second-feet).	Remarks.
1898.							
Mar. 2	G. R. Wadleigh	1985	5.34	244	0.59	144	
" 16	" "	1985	5.10	212	0.57	121	
Apr. 2	" "	1985	4.90	221	0.46	102	
" 6	" "	1985	7.87	400	1.28	514	
May 27	" "	1985	5.20	229	0.60	137	
Jun. 3	" "	1985	6.32	293	0.94	276	
" 20	" "	1985	7.56	363	0.76	277	
" 30	" "	1985	7.72	253	1.12	284	New Station, 1 mile
July 9	" "	1985	9.22	344	1.34	462	" " [above.
" 14	" "	1985	7.11	230	1.06	244	" "
" 21	" "	1985	8.86	312	1.37	428	" "
Aug. 3	" "	1985	7.41	233	1.15	267	" "
" 5	" "	1985	6.88	203	1.02	208	" "
" 13	G. H. Williams	1985	7.06	212	1.09	233	" "
" 17	" "	1985	6.74	201	1.02	206	" "
" 19	" "	1985	6.44	185	0.92	170	" "
Sep. 5	" "	65	5.30	226	0.65	148	Lower, or Old Station.
" 24	" "	65	6.30	167	1.02	170	Upper Station.
Oct. 6	" "	65	6.34	163	1.06	172	" "
" 11	" "	65	5.83	145	0.89	128	" "
" 19	" "	65	6.08	153	0.87	133	" "
Nov. 7	C. Hayman	65	5.48	132	0.79	104	" "
" 15	" "	65	6.18	160	0.87	139	" "
" 21	" "	65	6.80	196	1.11	218	" "
" 29	" "	65	7.67	250	1.37	343	" "
Dec. 7	" "	65	7.05	213	1.31	279	" "
" 17	" "	65	6.74	190	1.09	208	" "
" 27	" "	65	5.60	143	0.79	113	" "
" 31	" "	65	5.73	146	0.87	127	" "
1899.							
Jan. 2	H. S. Reed	65	8.00	253	1.51	382	" "
" 10	" "	65	6.75	193	1.14	221	" "
" 14	" "	65	7.69	246	1.46	361	" "
" 24	" "	65	6.57	189	1.02	192	" "
" 24	" "	65	5.98	278	0.87	242	Lower Station.
" 31	" "	65	5.78	155	0.78	121	Upper Station.
Feb. 6	" "	65	5.52	148	0.68	101	" "
" 14	" "	65	5.47	144	0.66	95	" "
" 17	" "	65	6.06	171	0.86	147	" "
" 20	" "	65	6.30	177	0.99	176	" "
" 27	" "	65	5.40	140	0.67	93	" "
Mar. 4	" "	65	5.30	134	0.59	79	" "
" 21	" "	65	4.50	204	0.46	93	Lower Station.
" 30	" "	65	4.25	186	0.42	77	" "

Rio Danta.

This stream is the outlet of the Florida lagoon, and flows into Rio San Juan about a mile above the mouth of the San Francisco. Its channel is narrow and deep, and contains considerable fallen timber, but is not subject to sudden changes of cross section. The current is usually sluggish, and is sometimes affected by the stage of water in Rio San Juan.

A gage was established on February 28, about 1½ miles above its mouth, and the following measurements of discharge have been made:

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO DANTA 1½ MILES ABOVE MOUTH.

Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. ft).	Mean velocity (ft. per second).	Discharge (second-ft).	Remarks.
1898.							
Feb. 28	W. W. Schlecht	93	3.98	134	1.03	138	
Mar. 8	" "	93	3.22	110	0.82	91	
" 18	" "	93	2.12	82	0.58	47	
" 28	" "	93	2.97	102	0.86	88	
Apr. 9	" "	93	4.23	148	1.07	159	
" 28	" "	93	2.24	76	0.70	53	
Jun. 15	C. Hayman	93	3.65	80	1.31	106	
" 27	" "	93	7.45	303	1.08	328	
July 8	" "	93	6.17	195	0.82	161	
" 19	" "	93	5.11	151	0.59	94	
" 28	" "	93	5.28	165	0.90	149	
Aug. 8	" "	93	4.63	147	0.80	118	
" 18	" "	93	4.48	135	0.90	121	
" 28	" "	93	4.21	125	0.84	104	
Sep. 8	" "	93	3.55	94	0.64	60	
" 27	" "	93	5.08	162	0.60	98	
Oct. 8	A. Ahrling	93	3.73	108	0.53	57	
" 18	" "	93	5.65	188	0.12	23	Backwater from San Juan.
" 29	" "	93	5.19	156	0.33	52	
Nov. 7	" "	93	4.01	115	0.36	42	
" 18	" "	93	11.60	432	1.27	549	
" 28	" "	93	7.18	231	0.82	190	
Dec. 8	" "	93	4.75	142	0.58	82	
" 17	" "	93	5.99	193	0.37	71	

Rio San Francisco.

The Canal Company's project provides for the construction of large embankments across the valleys of the Limpio, Chanchos, Nicholson, San Francisco and Danta, and involves the control of these streams, during construction, and receiving their discharge into the canal after completion. Their permanent control is also necessary if the canal is to follow the San Juan valley. A knowledge of their volume and fluctuations, as well as of the rainfall of the region, is therefore necessary.

The Rio San Francisco has its source on the southwestern slope of the range of hills known as the Eastern Divide, north of San Juan river. Its principal tributary is the Rio Chanchos,

which in turn receives the waters of Rio Limpio. The valley of the San Francisco is crossed by the proposed upper line of the canal, which follows for a considerable distance the valleys of the Chanchos and Limpio. The drainage area has never been definitely outlined and only meager information exists as to its extent. It is estimated, however, at about 65 square miles. The maximum discharge yet observed for the San Francisco above the confluence of Nicholson creek and Rio Chanchos is 866 cubic feet per second. A discharge of 888 cubic feet per second has been observed for the Chanchos and 100 for Nicholson creek. This would indicate a maximum during the time of observation of something less than 2000 for the San Francisco at its mouth. A rough tentative estimate based upon these figures and upon the greatest rainfall probable in this country would place the extreme maximum discharge which can occur at the mouth of the San Francisco at less than 4000 cubic feet per second. The certainty that this figure is ample is greatly strengthened by the nature of the lower portion of the San Francisco drainage basin, which includes a large area of perfectly flat land, which would be flooded in case of a discharge of 3000 cubic feet per second in the San Francisco, and which would act as a storage basin for floods exceeding that amount until they could be discharged through the channel of the river.

San Francisco Station.—On January 2 a station was established near the line of the proposed canal, about two miles by the river, above the crossing of the embankment line, and above the mouth of the Cañon Surprise.

On February 21 a gage rod was placed in the river at the crossing of the embankment line, and thereafter observations were taken at this point, which is below the mouth of Cañon Surprise. The channel is narrow and deep, is composed of hard clay and is not subject to change.

Measurements are given below for both stations; rating tables have been constructed, and daily discharges estimated for both, which are given below. Rainfall and hygrometer observations have also been taken.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO SAN FRANCISCO AT CENTER LINE OF CANAL.

Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. feet).	Mean velocity (ft. per second).	Discharge (second-feet).	Remarks.
Jan. 19.....	W. W. Schlecht...	93	13.52	310	1.02	319	Upper Station.
" 22.....	" " ...	93	15.12	373	1.19	445	" "
" 25.....	" " ...	93	11.97	238	0.91	208	" "
Feb. 3.....	N. P. Leary.....	93	15.83	407	1.16	471	" "
" 10.....	" "	93	12.75	264	0.83	220	" "
" 20.....	" "	93	10.60	168	0.74	124	" "
Mar. 2.....	W. W. Schlecht...	93	10.86	174	0.74	128	" "
" 10.....	" " ...	93	11.78	217	0.85	184	" "
" 19.....	" " ...	93	9.77	130	0.61	80	" "
" 29.....	" " ...	93	10.26	149	0.68	101	" "
Apr. 5.....	" " ...	93	15.90	397	1.54	610	" "
" 6.....	" " ...	93	16.48	429	1.32	569	" "
" 20.....	" " ...	93	9.82	134	0.60	81	" "
" 30.....	" " ...	93	9.36	113	0.59	67	" "

RATING TABLE FOR RIO SAN FRANCISCO AT CENTER LINE OF CANAL.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
8.6	40	10.8	128	13.0	278	15.2	455
8.7	43	10.9	133	13.1	286	15.3	464
8.8	46	11.0	138	13.2	294	15.4	473
8.9	49	11.1	144	13.3	302	15.5	482
9.0	52	11.2	150	13.4	310	15.6	491
9.1	55	11.3	156	13.5	318	15.7	500
9.2	58	11.4	162	13.6	326	15.8	509
9.3	61	11.5	168	13.7	334	15.9	518
9.4	64	11.6	174	13.8	342	16.0	527
9.5	68	11.7	180	13.9	350	16.1	536
9.6	72	11.8	186	14.0	358	16.2	545
9.7	76	11.9	193	14.1	366	16.3	554
9.8	80	12.0	200	14.2	374	16.4	563
9.9	84	12.1	207	14.3	382	16.5	572
10.0	88	12.2	214	14.4	390	16.6	581
10.1	93	12.3	222	14.5	398	16.7	590
10.2	98	12.4	230	14.6	406	16.8	599
10.3	103	12.5	238	14.7	414	16.9	608
10.4	108	12.6	246	14.8	422	17.0	617
10.5	113	12.7	254	14.9	430	17.1	626
10.6	118	12.8	262	15.0	438	17.2	635
10.7	123	12.9	270	15.1	446	17.3	644

DAILY GAGE HEIGHT OF RIO SAN FRANCISCO NEAR LINE OF EMBANKMENTS FOR 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.....	.....	11.00	6.76	4.58	4.46	7.34	9.85	8.13	5.96	6.19	5.92	9.18
2.....	15.30	14.91	6.12	4.43	5.66	5.87	11.80	9.75	5.88	8.87	5.55	9.33
3.....	15.40	15.88	5.59	4.29	4.74	5.32	13.42	9.32	5.56	6.38	5.34	8.40
4.....	15.85	15.61	5.41	4.55	4.64	4.94	13.06	8.29	5.55	6.85	5.39	7.86
5.....	15.16	17.12	8.02	10.27	7.17	4.73	12.27	7.82	5.29	6.50	5.46	7.52
6.....	13.85	16.51	8.32	11.62	6.54	4.52	11.37	7.50	5.23	6.31	5.53	7.70
7.....	15.38	14.30	6.39	8.05	5.98	4.62	9.46	7.35	5.84	5.95	7.15	8.27
8.....	14.25	14.41	6.07	7.31	5.07	4.92	8.96	8.69	5.23	6.05	10.45	7.40
9.....	13.82	14.12	7.26	6.38	4.77	5.06	10.83	8.46	5.26	6.47	8.48	7.46
10.....	14.10	12.75	7.60	5.78	4 62	4.48	11.06	8.63	5.20	6.06	7.56	9.10
11.....	13.98	12.40	6.05	5.61	5.69	4.61	10.95	7.70	8.90	5.72	7.32	11.52
12.....	12.82	12.10	5.60	6.19	6.92	4.47	9.44	8.35	6.89	6.15	6.99	10.65
13.....	12.07	12.50	5.36	5.59	5.45	7.04	8.65	8.80	11.44	6.96	8.86	9.05
14.....	11.65	11.70	5.11	5.12	4.96	7.79	7.91	10.82	10.31	6.56	10.93	7.90
15.....	.....	11.31	4.92	4.91	4.89	6.26	7.48	9.48	8.59	5.82	9.65	7.48
16.....	13.81	11.03	4.83	4.70	5.87	5.77	6.89	8.50	8.62	5.70	12.45	7.02
17.....	13.95	10.95	4.80	4.54	5.05	5.32	6.77	7.41	7.70	5.68	15.43	8.00
18.....	15.48	10.84	4.68	4.60	5.56	5.33	6.81	7.21	7.39	6.57	15.20	7.48
19.....	13.52	10.79	4.55	4.80	5.03	8.93	8.60	6.56	6.44	9.18	13.47	6.67
20.....	12.55	10.60	4.47	4.59	8.07	7.75	9.89	6.48	6.32	7.90	11.80	6.25
21.....	13.21	5.55	4.47	4.35	9.24	9.32	11.02	6.34	6.49	7.40	10.23	6.00
22.....	15.14	5.44	4.59	4.29	9.79	8.05	12.35	6.38	6.59	7.70	8.89	5.83
23.....	12.55	5.74	4.65	5.76	7.80	7.54	10.37	6.69	11.46	7.28	8.16	5.69
24.....	.....	5.31	4.48	5.32	6.67	9.95	8.73	7.14	8.67	8.29	7.59	5.50
25.....	11.99	5.37	5.30	4.75	5.91	11.63	9.02	6.61	7.47	7.50	7.66	5.33
26.....	11.85	5.88	6.46	4.48	5.45	10.39	9.33	6.70	9.44	8.70	8.40	5.42
27.....	12.05	6.71	5.91	4.79	5.36	11.33	8.49	6.76	7.93	8.30	9.55	5.38
28.....	11.45	8.36	6.35	4.50	5.27	10.85	8.46	6.64	7.45	7.21	11.55	5.34
29.....	11.60	.....	5.27	4.28	4.93	11.32	8.04	6.01	6.56	6.60	11.47	.....
30.....	11.51	.....	4.89	4.11	5.43	10.29	7.73	5.77	6.07	.....	.....	.....
31.....	11.20	.....	4.70	.....	5.77	.....	7.65	5.66	.....	.....	.....	.....

NOTE.—From January 2 to February 20 inclusive, rod read above Cañon Surprise. On February 20, rod moved to below the Cañon.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO SAN FRANCISCO AT LINE OF EMBANKMENTS.

Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. feet).	Mean velocity (ft. per second).	Discharge (second-feet).	Remarks.
1898.							
Mar. 2	W. W. Schlecht	93	5.99	171	0.87	148	Lower Station.
" 10	" "	93	6.80	213	0.97	206	" "
" 19	" "	93	4.52	114	0.72	83	" "
" 29	" "	93	5.21	141	0.76	108	" "
Apr. 6	" "	93	11.01	430	1.28	550	" "
" 20	" "	93	4.61	116	0.71	83	" "
" 30	" "	93	4.09	96	0.69	66	" "
May 5	Chas. Hayman	93	6.81	213	0.99	212	" "
" 9	" "	93	4.72	115	0.80	92	" "
" 12	" "	93	8.17	250	0.92	246	" "
" 16	" "	93	5.89	144	0.84	124	" "
" 21	" "	93	9.53	346	1.39	482	" "
" 25	" "	93	5.79	148	0.88	131	" "
" 31	" "	93	5.67	147	0.83	120	" "
June 8	" "	93	4.76	108	0.67	74	" "
" 11	" "	93	4.60	..	..	..	" "
" 17	" "	93	5.27	125	0.82	103	" "
" 21	" "	93	9.68	328	1.06	349	" "
" 25	" "	93	11.70	427	1.07	459	" "
July 6	" "	93	11.17	364	1.01	419	" "
" 21	" "	93	11.23	374	1.27	475	" "
" 30	" "	93	7.66	210	1.02	215	" "
Aug. 10	" "	93	8.98	280	1.13	326	" "
" 22	" "	93	6.35	164	0.87	143	" "
" 31	" "	93	5.61	147	0.75	111	" "
Sep. 10	" "	93	5.26	124	0.84	104	" "
" 20	" "	93	6.39	159	0.70	111	" "
" 26	" "	93	9.47	293	1.51	442	" "
Oct. 10	A. Ahrling	93	6.18	161	0.78	125	" "
" 14	" "	93	6.80	186	0.88	166	" "
" 20	" "	93	8.10	231	0.59	137	" "
" 24	" "	93	8.29	248	0.82	204	" "
" 28	" "	93	7.35	198	0.59	116	" "
Nov. 1	" "	93	5.95	131	0.61	67	" "
" 6	" "	93	5.43	120	0.65	78	" "
" 12	" "	93	6.98	180	0.67	121	" "
" 14	" "	93	10.87	385	0.82	317	" "
" 16	" "	93	12.53	456	1.13	515	" "
" 22	" "	93	8.89	261	1.00	263	" "
" 27	" "	93	9.22	282	1.10	310	" "

RATING TABLE FOR RIO SAN FRANCISCO AT LINE OF EMBANKMENTS.

This table is applicable only from February 24, 1898, to October 16, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
4.0	62	6.5	162	9.0	325	11.5	602
4.1	65	6.6	167	9.1	334	11.6	614
4.2	68	6.7	172	9.2	343	11.7	626
4.3	71	6.8	178	9.3	352	11.8	638
4.4	74	6.9	184	9.4	362	11.9	650
4.5	77	7.0	190	9.5	372	12.0	662
4.6	80	7.1	196	9.6	383	12.1	674
4.7	83	7.2	202	9.7	394	12.2	686
4.8	86	7.3	208	9.8	405	12.3	698
4.9	89	7.4	214	9.9	416	12.4	710
5.0	93	7.5	220	10.0	427	12.5	722
5.1	97	7.6	226	10.1	438	12.6	734
5.2	101	7.7	232	10.2	449	12.7	746
5.3	105	7.8	238	10.3	460	12.8	758
5.4	109	7.9	244	10.4	471	12.9	770
5.5	113	8.0	250	10.5	482	13.0	782
5.6	117	8.1	257	10.6	494	13.1	794
5.7	122	8.2	264	10.7	506	13.2	806
5.8	127	8.3	271	10.8	518	13.3	818
5.9	132	8.4	278	10.9	530	13.4	830
6.0	137	8.5	285	11.0	542	13.5	842
6.1	142	8.6	293	11.1	554	13.6	854
6.2	147	8.7	301	11.2	566	13.7	866
6.3	152	8.8	309	11.3	578		
6.4	157	8.9	317	11.4	590		

RATING TABLE FOR RIO SAN FRANCISCO AT LINE OF EMBANKMENTS.

This table is applicable only from Oct. 16, 1898, to November 30, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
5.0	40	7.7	183	10.4	360	13.1	556
5.1	45	7.8	189	10.5	367	12.2	564
5.2	50	7.9	195	10.6	374	13.3	572
5.3	55	8.0	201	10.7	381	13.4	580
5.4	60	8.1	207	10.8	388	13.5	588
5.5	65	8.2	213	10.9	395	13.6	596
5.6	70	8.3	219	11.0	402	13.7	604
5.7	75	8.4	225	11.1	409	13.8	612
5.8	80	8.5	231	11.2	416	13.9	620
5.9	85	8.6	237	11.3	423	14.0	628
6.0	90	8.7	243	11.4	430	14.1	636
6.1	95	8.8	249	11.5	437	14.2	644
6.2	100	8.9	255	11.6	444	14.3	652
6.3	105	9.0	262	11.7	451	14.4	660
6.4	110	9.1	269	11.8	458	14.5	668
6.5	115	9.2	276	11.9	465	14.6	676
6.6	120	9.3	283	12.0	472	14.7	684
6.7	125	9.4	290	12.1	479	14.8	692
6.8	130	9.5	297	12.2	486	14.9	700
6.9	135	9.6	304	12.3	493	15.0	708
7.0	141	9.7	311	12.4	500	15.1	716
7.1	147	9.8	318	12.5	508	15.2	724
7.2	153	9.9	325	12.6	516	15.3	732
7.3	159	10.0	332	12.7	524	15.4	740
7.4	165	10.1	339	12.8	532	15.5	748
7.5	171	10.2	346	12.9	540		
7.6	177	10.3	353	13.0	548		

ESTIMATED MONTHLY DISCHARGE OF RIO SAN FRANCISCO AT LINE OF EMBANKMENTS.

Month.	Discharge in Second-Feet.			Total in Acre-Feet.	Month	Discharge in Second-Feet.			Total in Acre-Feet.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
1898.					1898.				
									Brought forward, 72,000
January	514	150	314	19,310	July	866	176	407	25,025
February	628	108	251	13,940	August	545	120	236	14,510
March	272	76	127	7,810	September	595	102	220	13,090
April	590	70	128	7,620	October	313	75	162	9,960
May	417	76	148	9,100	November	745	57	279	16,600
June	626	76	239	14,220	December (1–28)	605	105	233	12,940
				72,000	Total				164,125

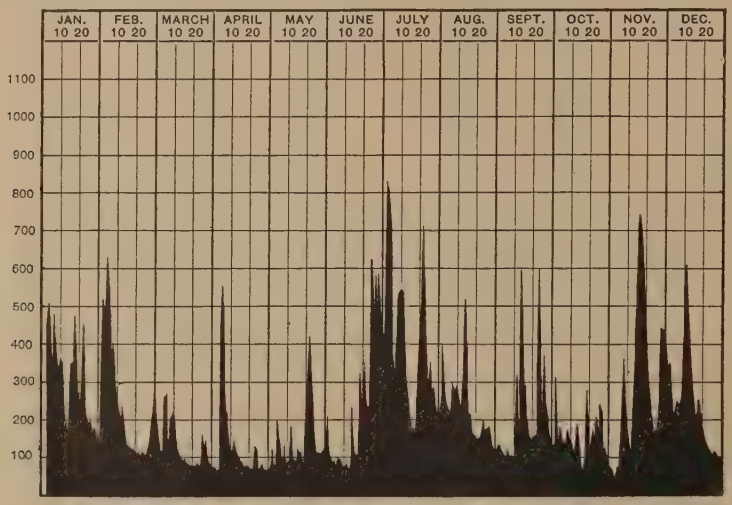


FIG. 6. Diagram of daily discharge of the Rio San Francisco at Embankment Line.

RIO LIMPIO.

On January 6 a gage was placed on the left bank of the Limpio about 200 yards above its mouth. It consists of a vertical plank driven in the bed of the stream, and spiked to a tree growing in the bank.

Three 60-penny nails driven into the tree to which the gage is fastened, and projecting about one inch, mark the elevation of eleven feet above datum.

Current meter measurements were made from the trunk of a tree felled across the river.

From January 17 daily observations were taken at this point until February 20, after which observations were taken two or three times per month.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO LIMPIO NEAR ITS MOUTH.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square ft.).	Mean velocity (feet per second).	Discharge (second-feet).	Remarks.
Jan. 21	H. S. Reed	Stk. 2	6.20	76	1.31	100	
" 28	" "	Stk. 2	4.27	34	0.93	32	
Feb. 3	W. W. Schlecht	Stk. 2	9.80	200	0.39	78	Backwater.
" 11	" "	Stk. 2	4.76	42	0.94	40	
" 19	" "	Stk. 2	3.88	22	1.15	25	
Mar. 12	" "	93	4.08	30	0.99	30	
" 23	" "	93	3.35	15	1.14	17	
Apr. 12	" "	93	4.05	30	1.08	32	
" 23	" "	93	3.94	21	1.05	22	
May 14	C. Hayman	93	3.80	25	0.92	23	
" 24	" "	93	3.83	24	1.10	25	
June 4	" "	93	3.66	22	0.95	22	
" 14	" "	93	3.72	21	0.89	19	
" 24	" "	93	3.45	16	0.69	11	
July 2	" "	93	7.96	116	0.52	60	
" 13	" "	93	4.11	20	1.08	22	
" 23	" "	93	5.29	42	1.05	44	
Aug. 3	" "	93	5.42	53	0.76	41	
" 13	" "	93	5.04	43	1.10	48	
" 23	" "	93	4.20	34	1.44	51	
Sep. 3	" "	93	3.49	19	1.28	24	
" 14	" "	93	5.02	46	0.77	35	
" 23	" "	93	7.19	118	0.32	38	Backwater.
Oct. 4	Alf. Ahrling	93	4.38	34	0.51	20	
" 13	" "	93	4.17	33	0.56	18	
" 22	" "	93	4.60	41	0.66	29	
Nov. 2	" "	93	3.51	18	0.88	16	
" 12	" "	93	3.93	30	0.73	22	
" 14	" "	93	5.24	48	0.79	38	
" 22	" "	93	4.48	37	0.78	29	
Dec. 3	" "	93	4.60	36	1.08	39	
" 13	" "	93	5.22	46	1.02	47	
" 27	" "	93	3.51	18	0.88	16	

RATING TABLE FOR RIO LIMPIO 100 YARDS ABOVE ITS MOUTH.

This table is applicable only from January 6, 1898, to February 20, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
2.9	11	4.7	88	6.5	105	8.3	195
3.0	12	4.8	40	6.6	110	8.4	200
3.1	13	4.9	43	6.7	115	8.5	205
3.2	14	5.0	46	6.8	120	8.6	210
3.3	15	5.1	49	6.9	125	8.7	215
3.4	16	5.2	52	7.0	130	8.8	220
3.5	17	5.3	56	7.1	135	8.9	225
3.6	18	5.4	60	7.2	140	9.0	230
3.7	19	5.5	64	7.3	145	9.1	235
3.8	20	5.6	68	7.4	150	9.2	240
3.9	22	5.7	72	7.5	155	9.3	245
4.0	24	5.8	76	7.6	160	9.4	250
4.1	26	5.9	80	7.7	165	9.5	255
4.2	28	6.0	84	7.8	170	9.6	260
4.3	30	6.1	88	7.9	175	9.7	265
4.4	32	6.2	92	8.0	180	9.8	270
4.5	34	6.3	96	8.1	185	9.9	275
4.6	36	6.4	100	8.2	190	10.0	280

ESTIMATED MONTHLY DISCHARGE OF RIO LIMPIO 100 YARDS ABOVE ITS MOUTH.

Month.	Discharge in Second-Feet.			Total in Acre-Feet.	Month.	Discharge in Second-Feet.			Total in Acre-Feet.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
January, 1898. (6–31).....	168	22	56	2,775	February, 1898. (1 to 20 incl.)...	283	20	82	3,250

Upper Station on the Rio Chanchos.

On January 17 a gage was placed on the right bank of the Chanchos, about 200 yards above the mouth of Rio Limpio. It consists of a vertical pine board, marked in feet and tenths, driven into the bed of the stream and spiked to a tree growing in the bank. Bench mark consists of three 60-penny nails driven in the tree to which gage was fastened, at 13-foot mark, projecting about three inches. Gagings were made by current meter from the trunk of a tree felled across the stream.

Daily observations were taken at this point until February 20, after which observations were taken two or three times a month.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO CHANCHOS AT UPPER STATION.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. feet).	Mean velocity (feet per sec.)	Discharge (second-feet).	Remarks.
Jan. 21	H. S. Reed	Stk. 2	6.07	245	0.92	226	
" 28	" "	Stk. 2	2.65	90	0.48	43	
Feb. 5	W. W. Schlecht	Stk. 2	8.00	334	0.96	321	
" 11	" "	Stk. 2	3.30	115	0.64	74	
" 19	" "	Stk. 2	2.26	70	0.53	37	
Mar. 12	" "	93	2.54	80	0.62	49	
" 23	" "	93	1.67	50	0.46	23	
Apr. 12	" "	93	2.48	78	0.60	47	
" 23	" "	93	2.50	78	0.60	47	
May 14	C. Hayman	93	2.21	66	0.58	38	
" 24	" "	93	2.34	76	0.64	48	
June 4	" "	93	1.78	46	0.46	22	
" 14	" "	93	2.05	52	0.63	33	
" 24	" "	93	1.92	53	0.55	29	
July 2	" "	93	6.68	243	1.22	297	
" 13	" "	93	2.60	73	0.63	46	
" 23	" "	93	3.87	121	0.75	91	
Aug. 3	" "	93	4.10	136	0.89	121	
" 13	" "	93	3.56	112	0.69	77	
" 23	" "	93	2.21	64	0.65	42	
Sept. 3	" "	93	1.78	46	0.47	23	
" 14	" "	93	3.67	113	0.83	93	
" 23	" "	93	6.05	230	1.13	260	
Oct. 4	" "	93	3.13	100	0.76	76	
" 13	" "	93	2.88	91	0.80	73	
" 22	" "	83	3.40	105	0.94	98	
Nov. 2	" "	93	2.00	55	0.50	28	
" 12	" "	93	2.52	76	0.74	57	
" 14	" "	93	3.91	115	0.95	109	
" 22	" "	93	2.94	84	0.74	62	
Dec. 3	" "	93	3.12	92	0.86	79	
" 13	" "	93	3.73	109	0.92	100	
" 27	" "	93	1.89	54	0.50	27	

RATING TABLE FOR RIO CHANCHOS ABOVE THE LIMPIO.

This table is applicable only from January 17, 1898, to February 21, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.
2.0	31	3.8	104	5.6	212	7.4	320
2.1	33	3.9	110	5.7	218	7.5	326
2.2	35	4.0	116	5.8	224	7.6	332
2.3	38	4.1	122	5.9	230	7.7	338
2.4	41	4.2	128	6.0	236	7.8	344
2.5	44	4.3	134	6.1	242	7.9	350
2.6	47	4.4	140	6.2	248	8.0	356
2.7	51	4.5	146	6.3	254	8.1	362
2.8	55	4.6	152	6.4	260	8.2	368
2.9	59	4.7	158	6.5	266	8.3	374
3.0	63	4.8	164	6.6	272	8.4	380
3.1	67	4.9	170	6.7	278	8.5	386
3.2	72	5.0	176	6.8	284	8.6	392
3.3	77	5.1	182	6.9	290	8.7	398
3.4	82	5.2	188	7.0	296	8.8	404
3.5	87	5.3	194	7.1	302	8.9	410
3.6	92	5.4	200	7.2	308		
3.7	98	5.5	206	7.3	314		

ESTIMATED MONTHLY DISCHARGE OF RIO CHANCHOS ABOVE THE LIMPIO.

Month, 1898.	Discharge in Second-Feet.			Total in Acre-Feet.	Month, 1898.	Discharge in Second-Feet.			Total in Acre-Feet.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
January 17-31..	252	36	96	2,850	February 1-20...	395	34	139	5,520

Lower Station on the Rio Chanchos.

A gage was placed on the left bank of the Rio Chanchos, about one-half mile above the point where the telegraph line intersects the river. It consists of a vertical pine board driven in the bed of the stream, and spiked to a tree growing on the bank. Bench mark consists of two 8-penny nails driven in a notch in a tree, 25 feet from the river bank at nearest point and 30 feet from gage rod. Tree has one smaller leaning against it.

Measurements of discharge were made from a huge tree trunk lying across the river one-half mile up stream from the gage.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO CHANCHOS AT LOWER STATION.

Date, 1898.	Hydrographer	Meter number.	Gage height (feet).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge (second-feet).	Remarks.
Jan. 10.....	N. P. Leary	93	5.98	321	1.26	404	
" 20.....	W. W. Schlecht....	Stk. 2	2.55	199	0.67	134	
" 27.....	"	Stk. 2	1.82	167	0.54	90	
Feb. 2.....	"	Stk. 2	7.23	455	1.48	674	
" 10.....	"	Stk. 2	3.19	204	0.80	162	
" 18.....	"	Stk. 2	0.92	144	0.33	48	
Mar. 7.....	"	93	1.16	143	0.56	80	
" 17.....	"	93	0.35	125	0.47	58	
" 26.....	"	93	0.73	139	0.48	67	

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO CHANCHOS AT LOWER STATION.—Cont.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge (second-feet).	Remarks.
Apr. 7	W. W. Schlecht	93	2.15	169	0.65	109	
" 16	"	93	0.16	123	0.37	46	
May 7	C. Hayman	93	1.17	124	0.57	71	
" 30	"	93	0.22	115	0.39	45	
June 8	"	93	0.05	94	0.33	32	
" 17	"	93	0.18	107	0.31	33	
" 29	"	95	5.78	264	0.84	228	
July 7	"	93	3.70	201	0.68	138	
" 16	"	93	1.51	127	0.40	51	
" 27	"	93	3.01	184	0.70	130	
Aug. 6	"	93	2.46	154	0.62	97	
" 17	"	93	2.00	146	6.46	67	
" 27	"	93	1.06	102	0.57	58	
Sept. 7	"	93	0.55	89	0.51	45	
" 17	"	93	2.89	137	0.47	63	
" 26	"	93	2.53	123	0.47	58	
Oct. 7	A. Ahrling	93	2.03	103	0.50	51	
" 10	"	93	1.15	99	0.53	53	
" 18	"	93	1.78	111	0.41	46	
" 26	"	93	3.74	169	0.61	103	
Nov. 6	"	93	0.79	95	0.36	34	
" 14	"	93	5.88	255	0.62	159	
" 16	"	93	7.43	354	1.41	498	
" 26	"	93	2.80	155	0.72	111	
Dec. 7	"	93	3.07	168	0.78	131	
" 17	"	93	2.90	148	0.62	92	
" 23	"	93	0.83	99	0.47	47	

RATING TABLE FOR RIO CHANCHOS AT LINE OF EMBANKMENTS.

This table is applicable only from January 7, 1898, to October 31, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.	Feet.	Second-ft.
−1.0	9	1.4	72	3.8	170	6.2	448
−0.9	11	1.5	75	3.9	175	6.3	470
−0.8	13	1.6	78	4.0	181	6.4	492
−0.7	15	1.7	81	4.1	187	6.5	514
−0.6	18	1.8	84	4.2	193	6.6	536
−0.5	21	1.9	87	4.3	200	6.7	558
−0.4	23	2.0	90	4.4	207	6·8	580
−0.3	26	2.1	94	4.5	215	6.9	602
−0.2	28	2.2	98	4.6	223	7.0	624
−0.1	31	2.3	102	4.7	232	7.1	646
0.0	33	2.4	106	4.8	241	7.2	668
0.1	35	2.5	110	4.9	251	7.3	690
0.2	37	2.6	114	5.0	261	7.4	712
0.3	39	2.7	118	5.1	272	7.5	734
0.4	42	2.8	122	5.2	283	7.6	756
0.5	45	2.9	126	5.3	295	7.7	778
0.6	48	3.0	130	5.4	308	7.8	800
0.7	51	3.1	135	5.5	322	7.9	822
0.8	54	3.2	140	5.6	337	8.0	844
0.9	57	3.3	145	5.7	353	8.1	866
1.0	60	3.4	150	5.8	370	8.2	888
1.1	63	3.5	155	5.9	388		
1.2	66	3.6	160	6.0	407		
1.3	69	3.7	165	6.1	427		

ESTIMATED MONTHLY DISCHARGE OF RIO CHANCHOS AT LINE OF EMBANKMENTS.

Month.	Discharge in Second-Feet.			Total in Acre-Feet.	Month.	Discharge in Second-Feet.			Total in Acre-Feet.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
1898.					1898.				Brought forward, 40,540
January	670	57	181	11,130	July	888	71	228	14,020
February	624	43	188	10,440	August	168	46	95	5,840
March	72	32	53	3,260	September	585	35	138	8,210
April	582	26	103	6,070	October	145	46	88	5,410
May	80	38	59	3,630	November	755	34	182	10,830
June	370	28	101	6,010	December	390	40	130	7,990
				40,540	Total				92,840

Nicholson Creek.

On January 17 a gage rod was placed in Nicholson creek a short distance below the telegraph line, and the following measurements of discharge were made, which give a fair idea of the size of the stream and its fluctuations. It will be noted that the relation between gage height and discharge is disturbed by back water in the San Francisco, but this does not affect the accuracy of the measurements given.

LIST OF DISCHARGE MEASUREMENTS MADE ON NICHOLSON CREEK BELOW TELEGRAPH LINE.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second-feet).	Remarks.
Jan. 21	N. P. Leary	93	8.67	149	0.67	100	
" 28	"	93	5.80	57	0.56	32	
Feb. 15	"	93	5.64	53	0.56	30	
" 21	W. W. Schlecht	93	5.02	34	0.69	24	
Mar. 6	"	93	6.25	67	0.54	36	
" 15	"	93	4.60	17	0.81	14	
" 25	"	93	4.70	24	0.85	21	
Apr. 15	"	93	4.46	21	0.82	17	
" 25	"	93	4.30	18	0.74	13	
May 7	C. Hayman	93	5.80	35	0.66	24	
" 18	"	93	4.64	21	0.72	16	
" 30	"	93	4.82	31	0.65	20	
June 8	"	93	4.38	15	0.64	10	
" 17	"	93	4.72	22	0.62	13	
" 29	"	93	9.52	175	0.48	84	
July 6	"	93	9.52	158	0.45	71	
" 14	"	93	6.85	70	0.36	25	
" 26	"	93	7.50	87	0.49	43	
Aug. 6	"	93	6.73	68	0.61	41	
" 15	"	93	8.22	104	0.42	43	
" 25	"	93	5.72	41	0.52	22	
Sept. 5	"	93	4.91	21	0.54	11	
" 15	"	93	7.20	78	0.32	25	
" 24	"	93	8.00	100	0.38	38	

Rio Sarapiqui.

The plan of canalizing the Rio San Juan, as sometimes proposed, involves the control of the waters of Rio Sarapiqui and of the sediment which it brings down from the mountains of Costa Rica.

On July 23 a gage was placed on the left bank of this river about five miles above its mouth. It is a vertical rod, graduated to feet and tenths, from zero to 13 feet, and spiked to a tree which hangs over the river. Another rod, graduated from 10 to 23 feet, is fastened to a tree about 300 yards up stream, on the same side of the river. At this latter place a galvanized steel cable is placed across the river, from which measurements of discharge are made with the use of a boat, and observations of sediment carried are also made.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO SARAPIQUI FIVE MILES ABOVE ITS MOUTH.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square ft.).	Mean velocity (feet per second).	Discharge (second-feet).	Remarks.
May 10	A. P. Davis	94	....	1,046	2.92	3,050	
July 12	"	94	....	3,686	2.65	10,762	
" 27	G. R. Wadleigh	1985	8.84	2,238	2.35	5,252	
Aug. 27	W. A. Smith	1985	8.51	1,922	2.43	4,677	
" 31	"	1985	8.11	1,765	2.28	4,014	
Sep. 3	"	1985	8.25	1,823	2.34	4,264	
" 9	H. W. Durham	1985	7.52	1,617	2.10	3,399	
" 12	"	1985	8.98	2,088	2.38	4,974	
" 13	"	1985	12.99	4,294	3.47	14,914	
" 14	"	1985	13.06	4,054	3.43	13,898	
" 21	"	1985	8.57	1,925	2.37	4,560	
" 24	"	1985	8.72	1,972	2.40	4,730	
" 27	"	1985	13.02	4,131	3.69	15,241	
Oct. 11	"	1985	11.95	3,388	3.42	11,598	
Dec. 21	"	1985	8.13	1,735	2.34	4,053	
1899.							
Jan. 9	"	1985	9.00	1,979	2.52	4,987	
" 13	"	1985	12.58	3,445	3.29	11,343	
" 16	"	1985	13.30	3,703	3.42	12,669	
" 21	"	1985	8.90	2,003	2.45	4,920	
" 25	"	1985	8.83	2,015	2.43	4,905	
" 28	"	1985	7.80	1,646	2.17	3,582	
" 31	"	1985	7.35	1,461	2.10	3,072	
Feb. 3	"	1985	7.25	1,406	2.04	2,862	
" 8	"	1985	7.25	1,450	2.03	2,943	
" 11	"	1985	7.04	1,399	1.94	2,711	
" 13	"	1985	18.40	5,563	4.81	26,731	
" 14	"	1985	15.20	4,459	3.79	16,892	
" 20	"	1985	11.20	2,869	2.99	8,582	
" 21	"	1985	8.78	1,938	2.32	4,501	
" 24	"	1985	11.37	2,967	2.96	8,780	
Mar. 4	"	1985	8.35	1,732	2.31	4,007	
" 8	"	1985	11.38	2,882	3.11	8,972	
" 11	"	1985	7.50	1,462	2.19	3,198	
" 16	"	1995	7.68	1,561	2.18	3,409	
" 18	"	1985	7.38	1,453	2.09	3,040	
" 22	"	1985	6.81	1,234	1.87	2,313	
" 25	"	1985	6.73	1,230	1.82	2,240	
" 29	"	1985	10.00	2,475	2.75	6,807	

RATING TABLE FOR RIO SARAPIQUI AT STATION FIVE MILES ABOVE ITS MOUTH.

This table is applicable only from July 23, 1898, to January 1, 1899.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.
7.2	3,140	9.7	7,090	12.2	12,590	14.7	18,090
7.3	3,210	9.8	7,310	12.3	12,810	14.8	18,310
7.4	3,280	9.9	7,530	12.4	13,030	14.9	18,530
7.5	3,350	10.0	7,750	12.5	13,250	15.0	18,750
7.6	3,420	10.1	7,970	12.6	13,470	15.1	18,970
7.7	3,500	10.2	8,190	12.7	13,690	15.2	19,190
7.8	3,590	10.3	8,410	12.8	13,910	15.3	19,410
7.9	3,690	10.4	8,630	12.9	14,130	15.4	19,630
8.0	3,800	10.5	8,850	13.0	14,350	15.5	19,850
8.1	3,930	10.6	9,070	13.1	14,570	15.6	20,070
8.2	4,070	10.7	9,290	13.2	14,790	15.7	20,290
8.3	4,220	10.8	9,510	13.3	15,010	15.8	20,510
8.4	4,380	10.9	9,730	13.4	15,230	15.9	20,730
8.5	4,550	11.0	9,950	13.5	15,450	16.0	20,950
8.6	4,730	11.1	10,170	13.6	15,670	16.1	21,170
8.7	4,920	11.2	10,390	13.7	15,890	16.2	21,390
8.8	5,120	11.3	10,610	13.8	16,110	16.3	21,610
8.9	5,330	11.4	10,830	13.9	16,330	16.4	21,830
9.0	5,550	11.5	11,050	14.0	16,550	16.5	22,050
9.1	5,770	11.6	11,270	14.1	16,770	16.6	22,270
9.2	5,990	11.7	11,490	14.2	16,990	16.7	22,490
9.3	6,210	11.8	11,710	14.3	17,210	16.8	22,710
9.4	6,430	11.9	11,930	14.4	17,430	16.9	22,930
9.5	6,650	12.0	12,150	14.5	17,650		
9.6	6,870	12.1	12,370	14.6	17,870		

RATING TABLE FOR RIO SARAPIQUI AT STATION FIVE MILES ABOVE ITS MOUTH.

This table is applicable only from January 1, 1899, to March 31, 1899.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.	Feet.	Second-feet.
6.5	2,020	8.6	4,560	10.7	7,785	12.8	11,690
6.6	2,140	8.7	4,700	10.8	7,940	12.9	11,890
6.7	2,260	8.8	4,850	10.9	8,100	13.0	12,090
6.8	2,380	8.9	5,000	11.0	8,260	13.1	12,290
6.9	2,500	9.0	5,150	11.1	8,430	13.2	12,490
7.0	2,620	9.1	5,300	11.2	8,600	13.3	12,690
7.1	2,740	9.2	5,450	11.3	8,780	13.4	12,890
7.2	2,860	9.3	5,600	11.4	8,960	13.5	13,090
7.3	2,980	9.4	5,750	11.5	9,140	13.6	13,290
7.4	3,100	9.5	5,900	11.6	9,330	13.7	13,490
7.5	3,220	9.6	6,060	11.7	9,520	13.8	13,690
7.6	3,340	9.7	6,220	11.8	9,710	13.9	13,890
7.7	3,460	9.8	6,380	11.9	9,900	14.0	14,090
7.8	3,580	9.9	6,540	12.0	10,090	14.1	14,290
7.9	3,700	10.0	6,700	12.1	10,290	14.2	14,500
8.0	3,820	10.1	6,855	12.2	10,490	14.3	14,720
8.1	3,940	10.2	7,010	12.3	0,690	14.4	14,840
8.2	4,060	10.3	7,165	12.4	0,890	14.5	15,170
8.3	4,180	10.4	7,320	12.5	1,090	14.6	15,400
8.4	4,305	10.5	7,475	12.6	1,290		
8.5	4,430	10.6	7,630	12.7	11,490		

ESTIMATED MONTHLY DISCHARGE OF RIO SARAPIQUI FIVE MILES ABOVE ITS MOUTH.
Drainage area, 1,100 square miles, approximately.

Month.	Discharge in Second-feet.			Total for the month in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per sq. mile.
1898.						
July (23–31)	.....	.....	5,890	.....	.....	.....
August (1–5 and 18–31 incl.)	.....	.....	5,550	341,250	5.82	5.05
September	13,140	3,360	5,890	350,780	5.97	5.35
October	14,570	4,100	8,240	507,560	8.65	7.50
November	30,000	4,640	11,700	696,200	11.87	10.64
December	21,610	3,150	6,650	408,890	6.98	6.05
1899.						
January	18,580	3,000	5,420	333,260	5.68	4.93
February	27,100	2,710	5,200	288,800	4.93	4.73
March	8,960	2,280	3,350	205,980	3.98	3.45

Rio Taura.

The waters of the San Juan river have two principal outlets, the southern called the Rio Colorado, and the northern, called the lower San Juan. The latter stream sends out another distributary which empties into the ocean between the two larger, and is called the Taura. It seems, however, that a portion of the course of the Taura is, during the season of low water, higher than the water in the San Juan, and becomes a tributary of the latter. It was visited on May 6, 1898, and was at that time discharging 25 cubic feet per second into the San Juan. On the same day the discharge of the San Juan below the Taura was 1112 cubic feet per second. The discharge at Ochoa on the same date was 16,950 cubic feet per second.

On July 13 the Taura was flowing away from the San Juan and its volume 200 yards below its exit was 2234 cubic feet per second. On this day the discharge of the San Juan at Ochoa was 46,000 cubic feet per second.

The condition in May of the Taura flowing toward the San Juan was apparently quite anomalous, the mouth at the coast being closed by a dike of sand built by the waves. The normal condition of the Taura is that of a minor distributary of the San Juan.

Rio Deseado.

This is a small stream rising in the ridge of hills, known in canal literature as the "Eastern Divide."

According to the company's location the canal is to follow the valley of the Deseado for a considerable distance and the plan involves the control and diversion of the waters of this stream. Three locks and several high embankments are to be constructed in this valley and the volume of the river and the amount of rainfall in this vicinity become important facts, an approximate knowledge of which is necessary to an intelligent discussion of plans and estimate of cost.

On the 25th of December, 1897, a gage was placed in the Deseado at a point about five miles above its mouth, measured along the course of the stream; a rain gage was also established at this point, and observations of river height, rainfall, temperature and humidity were begun by Mr. W. M. Barton.

Subsequent measurements of discharge showed that no definite relation could be established between gage height and discharge of the stream, although the channel consists of hard clay and is not changeable. The erratic changes in velocity which the stream exhibited at this point are doubtless due to the fact that it runs through

swampy country on very flat slope. Though there are no definite tributaries anywhere near the gaging station, yet heavy rains in the swamps serve to back the water in the Deseado, if occurring below the station, and to accelerate its velocity if occurring above.

On March 4 observations of gage height were begun some distance above at "Camp No. 7" near the site of the proposed Lock No. 1, and the following discharge measurements were made at that point, and from these a rating table was constructed and the table of discharges estimated.

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO DESEADO AT CAMP BARTON.

Date. 1898.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (sq. ft.).	Mean velocity (ft. per sec.).	Discharge (second-feet).
Feb. 26	A. P. Davis	Stk. 2	7.85	772	0.63	489
Mar. 8	W. M. Barton	2	8.70	823	0.12	99
" 15	L. E. Lannan	2	7.71	711	0.03	19
April 5	"	2	7.69	730	0.63	462
" 12	"	2	8.03	744	0.12	97
" 21	"	2	4.85	507	0.06	34
" 26	"	2	5.75	575	0.10	51
May 3	"	2	6.28	603	0.18	107
" 7	"	2	7.12	671	0.14	92
" 12	"	2	6.63	634	0.35	213
" 18	"	2	5.68	570	0.05	31
" 24	J. C. Elson	2	6.82	639	0.09	58
" 31	"	2	6.32	609	0.36	220
June 3	"	2	6.80	625	0.06	43
" 11	"	2	4.90	491	0.07	35
" 14	"	2	7.15	662	0.23	156
" 16	"	2	7.28	649	0.15	102
" 20	"	2	6.80	636	0.06	43
" 25	"	2	10.12	922	0.68	634
" 28	"	2	10.26	928	0.18	173
July 8	"	2	10.80	958	0.22	211
" 12	"	2	10.15	919	0.23	219
" 16	"	2	8.88	822	0.19	159
" 21	"	2	11.83	1026	0.53	550
Aug. 6	"	2	10.19	918	0.22	208
" 9	"	2	10.59	926	0.33	309
" 13	"	2	10.51	932	0.14	135
" 16	"	2	10.95	891	0.10	93
" 26	"	2	7.42	681	0.14	100
Sept. 2	"	2	6.70	616	0.07	45
" 10	"	2	6.15	577	0.05	27
" 14	"	2	7.19	657	0.37	243
" 19	"	2	6.66	610	0.11	69
" 24	"	2	6.60	601	0.10	63
Oct. 6	"	2	6.10	560	0.13	71
" 10	"	2	6.78	597	0.09	56
" 15	"	2	6.94	602	0.10	64
" 22	"	2	6.99	622	0.24	151
" 26	"	2	8.60	738	0.27	199
" 31	"	2	7.69	668	0.07	46
Nov. 10	"	2	9.20	788	0.14	111
" 16	"	2	11.78	950	0.45	429
" 18	"	2	14.28	1153	0.50	577
" 22	"	2	11.61	940	0.15	144
" 26	"	2	11.06	913	0.35	317
" 29	"	2	12.49	1030	0.31	319
Dec. 1	"	2	12.26	1004	0.26	264
" 8	"	2	11.18	936	0.24	229
" 13	"	2	12.33	1012	0.23	232

LIST OF DISCHARGE MEASUREMENTS MADE ON RIO DESEADO AT CAMP NO. 7.

Date. 1898.	Hydrographer.	Meter Number.	Gage height (feet).	Area of section (sq. ft.).	Mean velocity (ft. per. sec.).	Discharge (second-feet).
Mar. 8	W. M. Barton	Stk. 2	5.60	220	0.84	185
" 12	L. E. Lannan	2	5.65	224	0.78	175
" 18	"	2	4.85	172	0.41	70
" 25	"	2	5.56	223	0.54	121
April 1	"	2	4.68	171	0.38	64
" 6	"	2	7.05	298	0.80	238
" 11	"	2	5.06	195	0.38	74
" 18	"	2	4.44	157	0.21	33
" 25	"	2	4.47	167	0.30	50
May 2	"	2	4.88	184	0.41	75
" 9	"	2	4.65	173	0.53	91
" 16	"	2	5.08	195	0.51	100
" 23	"	2	4.83	179	0.38	68
" 30	J. C. Elson	2	4.10	143	0.59	86
June 6	"	2	3.95	110	0.45	50
" 13	"	2	5.08	194	0.86	168
" 21	"	2	4.88	186	0.45	85
July 1	"	2	12.64	613	1.30	798
" 9	"	2	6.78	293	0.79	232
" 15	"	2	5.48	205	0.55	113
Aug. 5	"	2	6.72	279	0.78	219
" 12	"	2	6.85	284	0.79	227
" 17	"	2	5.76	225	0.59	135
" 23	"	2	5.00	178	0.58	103
" 30	"	2	4.58	155	0.61	95
Sept. 9	"	2	4.52	161	0.57	92
" 13	"	2	4.85	170	0.76	130
" 19	"	2	4.09	137	0.39	59
" 23	"	2	5.56	214	0.61	132
" 26	"	2	4.01	132	0.37	49
" 30	"	2	3.64	115	0.37	42
Oct. 7	"	2	4.17	140	0.46	65
" 10	"	2	4.49	155	0.51	80
" 17	"	2	4.05	134	0.28	38
" 21	"	2	3.75	119	0.46	56
" 24	"	2	5.95	242	0.66	160
" 29	"	2	4.32	148	0.46	68
Nov. 4	"	2	4.20	142	0.54	77
" 11	"	2	5.09	186	0.61	114
" 15	"	2	6.08	248	0.76	188
" 19	"	2	8.42	360	0.85	305
" 21	"	2	6.81	280	0.78	220
" 28	"	2	11.98	544	1.13	615
Dec. 2	"	2	7.84	323	0.89	287
" 9	"	2	7.22	294	0.84	247
" 12	"	2	8.22	350	0.93	324
" 16	"	2	6.08	227	0.69	156
" 19	"	2	5.50	191	0.69	134

RATING TABLE FOR RIO DESEADO AT CAMP NO. 7.

This table is applicable only from March 4, 1898, to December 31, 1898.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	Second-ft.	Feet.	Second ft.	Feet.	Second-ft.	Feet.	Second-ft.
3.0	26	5.6	130	8.2	350	10.8	610
3.1	28	5.7	137	8.3	360	10.9	620
3.2	30	5.8	144	8.4	370	11.0	630
3.3	32	5.9	151	8.5	380	11.1	640
3.4	34	6.0	159	8.6	390	11.2	650
3.5	36	6.1	167	8.7	400	11.3	660
3.6	38	6.2	175	8.8	410	11.4	670
3.7	41	6.3	183	8.9	420	11.5	680
3.8	44	6.4	191	9.0	430	11.6	690
3.9	47	6.5	199	9.1	440	11.7	700
4.0	50	6.6	207	9.2	450	11.8	710
4.1	53	6.7	215	9.3	460	11.9	720
4.2	56	6.8	224	9.4	470	12.0	730
4.3	59	6.9	233	9.5	480	12.1	740
4.4	62	7.0	242	9.6	490	12.2	750
4.5	66	7.1	251	9.7	500	12.3	760
4.6	70	7.2	260	9.8	510	12.4	770
4.7	75	7.3	269	9.9	520	12.5	780
4.8	80	7.4	278	10.0	530	12.6	790
4.9	85	7.5	287	10.1	540	12.7	800
5.0	91	7.6	296	10.2	550	12.8	810
5.1	97	7.7	305	10.3	560	12.9	820
5.2	103	7.8	314	10.4	570	13.0	830
5.3	109	7.9	323	10.5	580	13.1	840
5.4	116	8.0	332	10.6	590	13.2	850
5.5	123	8.1	341	10.7	600	13.3	860

ESTIMATED MONTHLY DISCHARGE OF RIO DESEADO AT CAMP NO. 7.

Month.	Discharge in Second-feet. Maximum.	Minimum.	Mean.	Total for Month in Acre-feet.	Month.	Discharge in Second-feet. Maximum.	Minimum.	Mean.	Total for Month in Acre-feet.
1898.					1898.				Brought forward, 48,388
March	135	68	107	6,579	August	482	70	200	12,300
April	462	34	111	6,605	September	243	27	78	4,640
May	223	31	97	5,964	October	278	42	99	6,090
June	267	30	137	8,150	November	854	77	322	19,160
July	794	122	343	21,090	December	324	90	221	13,590
				48,388	Total				104,168

MISCELLANEOUS DISCHARGE MEASUREMENTS IN NICARAGUA.

Made by A. P. Davis, 1898.

Date.	Stream.	Locality.	Meter number.	Gage height (feet).	Area of sec. (sq. ft.).	Mean veloc. (ft. per sec.).	Discharge (sec. ft.).
Jan. 18	Las Lajas	At mouth	94	7.88	2.8	1.46	4.1
" 18	Guiscoyol	2 miles up	94	....	6.1	0 32	2.0
" 30	Jicoral	Jicoral	94	....	20.0	0 47	9.4
May 12	Machuca	½ mile up	94	....	68.0	1.10	75.0
July 9	Machuca	2 miles up	94	....	156.0	1.70	266.0
June 21	Ollate	8 " "	94	2.60	1079.0	3.94	4258.0

RECORD OF RIVER GAGINGS FOR VELOCITY AND VOLUME.

Taken from Appendix C of Report of Nicaragua Canal Board, 1895.

River.	Locality.	Date.	Authority.	Area of cross sec. (sq. ft.).	Velocity per sec. (ft.).	Discharge per sec. (cu. ft.).	Remarks.
San Juan	Fort San Carlos	June 5, 1850	O. W. Childs	.....	.....	11,930	Lake Nicaragua at an elevation 103.07, low stage.
"	Immediately above mouth of San Carlos River	July 15, 1850	"	.....	.....	19,300	Medium stage.
"	Immediately below mouth of San Carlos River	July 15, 1850	"	.....	.....	35,747	" "
"	Immediately above mouth of Sarapiqui River	Aug. 8, 1850	"	.....	.....	39,526	" "
"	Immediately below mouth of Sarapiqui River	Aug. 8, 1850	"	.....	.....	52,792	" "
"	Immediately above head of Colorado River	Aug. 20, 1850	"	.....	.....	54,380	" "
Colorado River	.....	Aug. 20, 1850	"	.....	.....	42,056	" "
Lower San Juan	.....	Aug. 20, 1850	"	.....	.....	12,324	" " Ele. of Lake Nicaragua Sept. 19, 1850, 105.62.
San Juan	Above Toro Rapids	April 26, 1873	Lull	.....	.....	12,096	Ele. of Lake Nicaragua, 102.28, low stage.
San Juan	Below mouth of Poco Sound	April 30, 1873	"	.....	.....	11,390	" "
"	Above mouth of Santa Cruz	May 1, 1873	"	.....	.....	11,630	" "
"	Below mouth of Santa Cruz	May 2, 1873	"	.....	.....	12,453	" "
"	Above Mico Rapids	May 6, 1873	"	.....	.....	12,943	" "
"	Above mouth of San Carlos	May 10, 1873	"	.....	.....	13,206	" "
"	Above mouth of Sarapiqui	May 16, 1873	"	.....	.....	14,572	" "
"	Below mouth of Sarapiqui	May 16, 1873	"	.....	.....	16,770	" "
Colorado	.....	May 19, 1873	"	.....	.....	16,190	" "
Lower San Juan	.....	May 20, 1873	"	.....	.....	607	" "
San Juan	Between mouth of San Carlos and Ochoa	May 21 to 26, 1888	Canal Co., by J. H. Covode	11,310	3.665	41,451	Medium stage.

RECORD OF RIVER GAGINGS FOR VELOCITY AND VOLUME.—Continued.

River.	Locality.	Date.	Authority.	Area of cross sec. (sq. ft.).	Velocity per sec. (ft.).	Discharge per sec. (cu. ft.).	Remarks.
San Juan	Fort San Carlos	May 27, 1895	Nic. Canal Board	7,480	.....	9,420	Lake at elev. 101.07 ft., velocities meas'd with floats immersed 5′; low stage, coefficient, 0.9.
"	Below mouth of Sarapiqui	June 20, 1895	"	21,500	3.50	60,200	Using surface velocity low stage, coefficient, 0.8.
San Carlos	Immediately above mouth	July 15, 1850	O. W. Childs	.....	.....	16,447	Medium stage.
"	.....	Nov. 20, 1888	Canal Co. by J. F. Le Baron	.....	.....	7,844	" "
Sarapiqui	Immediately above mouth	Aug. 8, 1850	O. W. Childs	.....	.....	13,266	" "
Danta	300′ above mouth	Mar. 21, 1888	Canal Co. by J. F. Le Baron	87.5	0.40	35	Low stage.
"	"	July 16, 1888	"	611	1.25	764	High stage.
San Francisco	Below mouth of Chanchos	Mar. 23, 1888	"	290	0.60	174	Using surface velocity, low stage.
"	Camp San Francisco	June 14, 1895	Nic. Canal Board	221	1.70	376	" "
"	200′ below Camp San Francisco	June 14, 1895	"	303	1.05	318	" "
"	Below mouth of Chanchos	June 15, 1895	"	515	1.30	669	" "
Nicholson	Embankment Crossing	June 14, 1895	"	100	1.70	170	" "
Chanchos	"	June 15, 1895	"	209	1.60	334	" "
Limpio	Just below Camp Carmen	June 15, 1895	"	45	1.30	58	" "
"	At Camp Carmen	June 15, 1895	"	34	1.90	65	" "
"	Just above junction with the Lindo	June 16, 1895	"	9	1.80	16	" "
Lindo	Just above junction with Limpio	June 16, 1895	"	10.4	1.60	17	" "
Deseado	New site of Virginia Dam	June 17, 1895	"	50	3.00	150	" "
"	1500′ below Camp Menocal	June 18, 1895	"	277	2.30	637	" "
"	Near Camp No. 7	June 18, 1895	"	484	1.5	727	" "
"	Near Lock No. 1	Dec. 14, 1892	Canal Co., by Boyd Ehle	.....	.....	285	Water surface elevation 12.28, medium stage.

Rainfall.

Observations of rainfall were made at each river station, the form of gage used at most of the stations being a metal funnel which caught the rain and discharged it into a bottle, from which it was measured in a graduate bearing a known relation to the diameter of the funnel. The gage was always placed in a position as exposed as possible, but nearly always this was a small clearing in the forest, which was still well sheltered from the wind.

One of the most remarkable characteristics of Nicaragua is its rainfall, and the radical and striking differences in the climate of the east and west coasts with reference thereto.

The diagram (Plate XI), shows graphically the contrast in the distribution of rainfall at Brito near the Pacific coast and on the Rio Deseado, a short distance inland from Greytown. From this it will be seen that there is no definite dry season on the eastern coast, but that rain may be expected any day in the year, and the expectation will seldom be disappointed.

At Brito, on the contrary, there is no rain from the beginning of the record in January till the middle of May, when the rainy season begins, but the region is subject to violent downpours during the rainy season, the precipitation for a single day observed at this station on the 22d day of May being 5.6 inches.

No less remarkable is the excessive aggregate of rainfall in a limited district of which the nucleus seems to be in the vicinity of Greytown. The annual rainfall at this point, as deduced from the mean of four years' observation, is about 250 inches, while that at Bluefields is only about 90, at Port Limon somewhat less, and at San José de Costa Rica about 68. While there is a slight increase of rainfall with altitude on the headwaters of the Deseado and Limpio, yet in general it may be said that the rainfall decreases as we pass up the San Juan, as shown by the diagram, Plate XIII. No definite limits can be assigned to this district of excessive rainfall, nor is it known in what ratio the precipitation decreases to the northward and southward. So far as known, no satisfactory theory has yet been advanced to account for this local phenomenon.

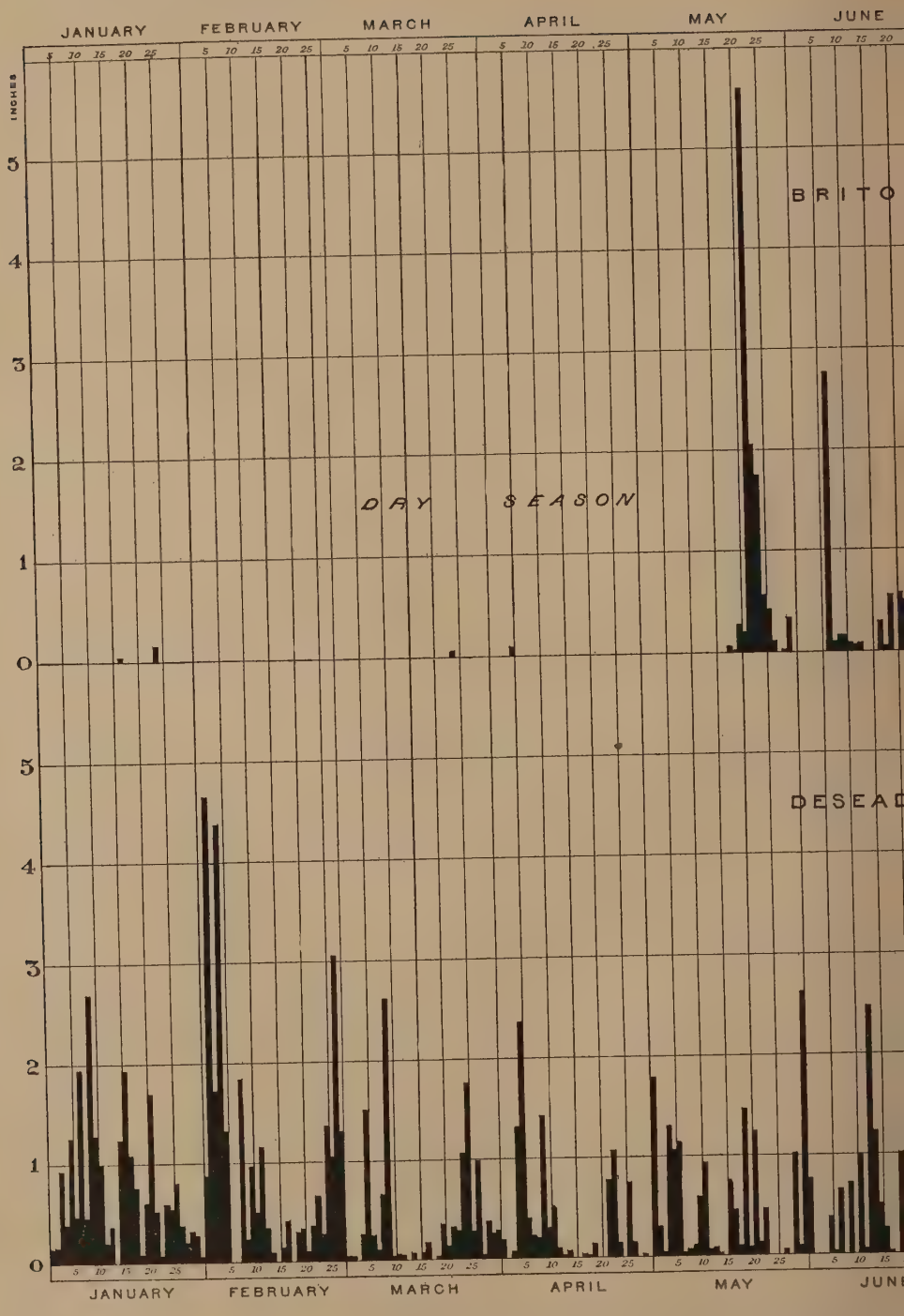
Mr. William Climie reports a rainfall of nine inches in nine hours at Nandaime, a small town south of Granada. No such precipitation has been observed by this party, however, the heaviest rainfalls in 1898 being as follows:

Station.	Date.	Time.	Inches of Rain.
Morrito,	Sept. 14,	10 hrs.	4.65
Ft. San Carlos,	June 18,	¾ hr.	1.83
Sabalos,	June 18,	1¼ hr.	2.32
Sabalos,	Oct. 27,	2 hrs.	3.11
Rio San Carlos,	June 21,	1 hr.	1.55
Rio San Francisco,	Nov. 7,	night,	3.70

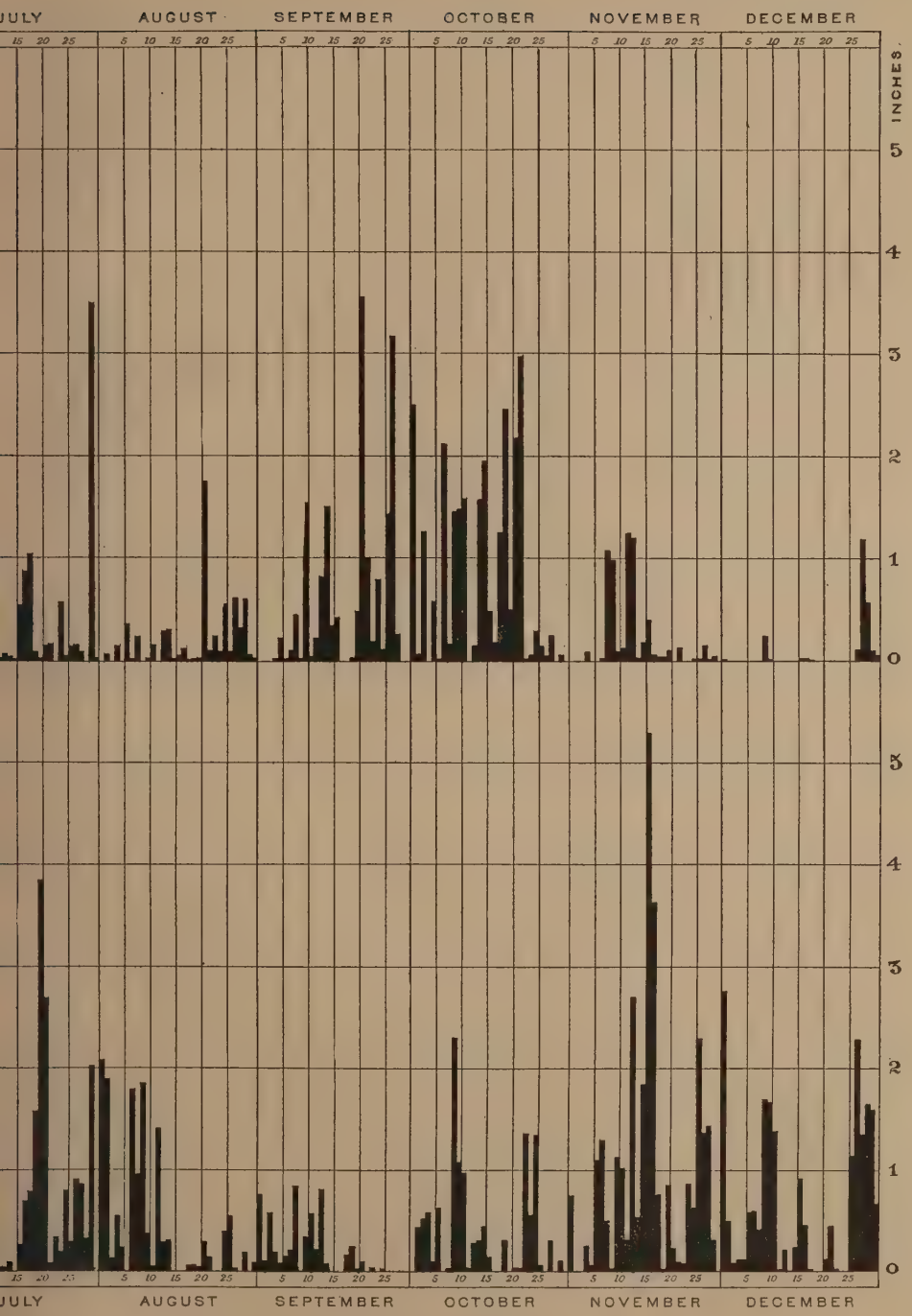
The heaviest general rain storm of the season began in the night following November 15, 1898, and passed westward, a heavy precipitation being shown at all stations east of Lake Nicaragua. The observed quantities are as follows:

Greytown	4.85	inches	fell in	24 hours.
"	7.92	"	" 48	"
Rio Deseado	6.26	"	" 24	"
Rio San Francisco	6.51	"	" 24	"
Ochoa	3.60	"	"	one night.
Sarapiqui	3.45	"	" "	"
Fort San Carlos	1.05	"	" "	day.

The following records of heavy rainfalls were compiled by the Canal Board of 1895 and are published in Appendix E of their report.



COMPARISON OF DAILY RAINFALL ON RIO DESEADO,



ERN COAST, AND BRITO, NEAR WESTERN COAST, 1898.

LARGE MONTHLY RAINFALLS AT GREYTOWN.

Month.	Inches.
November, 1889 (in 24 days)	50.70
December, 1889	64.39
June, 1890	41.56
July, 1890	52.59
August, 1890	36.61
December, 1890	41.65
December, 1891	32.74
May, 1892	50.88
July, 1892	38.96
November, 1892	36.93

LARGE DAILY RAINFALLS AT GREYTOWN.

Date.	Inches.
July 1, 1890	4.20
July 2, 1890	4.31
July 11, 1890	4.18
July 12, 1890	2.19
July 13, 1890	5.02
July 14, 1890	4.66
July 15, 1890	2.57
September 7, 1890	4.05
October 9, 1890	4.00
November 5, 1890	4.10
December 27, 1890	7.65
January 20, 1891	4.35
April 28, 1891	5.75
June 5, 1891	3.83
June 6, 1891	4.95
Total for 2 days	8.78
June 22, 1891 (9 hours)	4.51
July 18, 1891 (9 hours)	8.17
December 8, 1891	4.05
May 1, 1892	5.08
May 2, 1892	4.95
May 3, 1892	4.57
May 4, 1892	1.62
May 5, 1892	5.10
May 6, 1892	5.80
May 7, 1892	4.10
May 8, 1892	4.20
Total for 8 days	35.42
July 23, 1892	5.30
October 29, 1892	5.78
October 30, 1892	3.50
October 31, 1892	8.02
Total for 3 days	17.30
November 20, 1892	5.12
December 5, 1892	8.95
June 3, 1893	4.00
June 19, 1893	5.00

LARGE DAILY RAINFALLS AT CAMP No. 4.

Date.	Inches.
July –, 1890	5.25
July 5, 1891	7.70
July 6, 1891	6.70

LARGE DAILY RAINFALLS AT CAMP CARAZO.

Date.	Inches.
June 27, 1888	4.60
December 4, 1888	4.00
May 21, 1889	2.90
October 20, 1889	3.00
December 19, 1889	2.90
December 28, 1889	3.50
January 22, 1890	3.00

LARGE DAILY RAINFALL AT SILICO LAKE.

Date.	Inches.
April –, 1890	7.12

DAILY RAINFALL AT BRITO AND TOLA FOR 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.....	0.00	0.00	0.00	0.00	0.00	0.00	.54	0.00	0.00	2.50	0.00	0.02
2.....	0.00	0.00	0.00	0.00	0.00	0.00	.32	.06	0.00	.06	0.00	0.00
3.....	0.00	0.00	0.00	0.00	0.00	0.00	.65	.00	0.00	1.25	0.00	0.00
4.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.13	.01	0.00	.09	0.00
5.....	0.00	0 00	0.00	.08	0.00	0.00	0.00	0.00	.22	.57	0.00	0.00
6.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.35	.02	.01	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	2.75	.98	.02	.10	2.13	0.02	0.00
8.....	0.00	0.00	0.00	0.00	0.00	.07	.01	.23	.45	.14	1.08	0.00
9.....	0.00	0.00	0.00	0.00	0.00	0.00	.26	0.01	.02	1.45	.99	.25
10.....	0.00	0.00	0.00	0.00	0.00	.14	.84	.03	1.53	1.47	.08	.02
11.....	0.00	0.00	0.00	0.00	0.00	.08	.36	.16	.03	1.59	.12	0.00
12.....	0.00	0.00	0.00	0.00	0.00	.06	.01	0.00	.21	0.00	1.24	0.00
13.....	0.00	0.00	0.00	0.00	0.00	.08	.07	.29	.80	.14	1.20	0.00
14.....	0.00	0.00	0.00	0.00	0.00	0.00	.03	.31	1.50	1.58	.02	0.00
15.....	0.00	0.00	0.00	0.00	0.00	0.00	.01	.01	.34	1.96	.19	0.00
16.....	0.00	0.00	0.00	0.00	0.00	0.00	.54	.04	.42	.48	.39	.03
17.....	0.04	0.00	0.00	0.00	0.00	.30	.88	.12	0.00	.17	.05	.03
18.....	0.00	0.00	0.00	0.00	.04	.04	1.04	.01	0.00	1.25	.04	.02
19.....	0.00	0.00	0.00	0.00	.02	.55	.09	.01	.02	2.45	.04	0.00
20.....	0.00	0.00	0.00	0.00	.28	0.00	.02	.02	.47	.50	.09	0.00
21.....	0.00	0.00	0.00	0.00	.20	.58	.13	1.76	3.54	2.19	0.00	0.00
22.....	0.00	0.00	0.00	0.00	5.58	.50	.15	.10	1.00	2.96	.11	0.00
23.....	0.00	0.00	0.00	0.00	2.04	.01	0.00	.23	.17	.02	0.00	0.00
24.....	.15	0.00	.08	0.00	1.73	1.40	.58	.08	.79	.05	0.00	0.00
25.....	0.00	0.00	0.00	0.00	.56	.06	.04	.53	.10	.30	.02	0.00
26.....	.06	0.00	0.00	0.00	.41	2.31	.13	.09	1.43	.15	.02	0.00
27.....	0.00	0.00	0.00	0.00	0.10	1.76	.15	.61	3.18	.05	.15	.12
28.....	0.00	0.00	0.00	0.00	0.00	4.13	.09	.31	.25	.23	.02	1.19
29.....	0.00	0.00	0.00	0.00	.01	.04	0.00	.59	0.00	0.00	.05	.58
30.....	0.00	0.00	0.00	0.00	.33	0.00	3.49	.05	0.00	.05	0.00	.10
31.....	0.00	0.00	0.00	....	0.00	....	.01	.02	....	0.00	....	.05
Totals..	.25	0.00	.08	.08	11.30	14.86	11.42	6.17	16.60	25.70	6.01	2.41

DAILY RAINFALL AT RIVAS FOR 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.07
2.....	0.00	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.44	0.34	0.00	0.00
3.....	0.00	0.00	0.00	0.00	0.00	0.00	0.40	1.00	0.40	1.60	0.00	0.00
4.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.06	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	0.09	0.00	0.00
6.....	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.14	0.23	0.00	0.00
7.....	0.00	0.00	0.04	0.00	0.00	0.04	1.97	0.80	0.21	0.08	0.10	0.00
8.....	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.06	1.91	2.76	0.00
9.....	0.00	0.00	0.00	0.00	0.00	0.15	0.78	0.00	1.38	0.80	0.04	0.20
10.....	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.00	0.00	0.63	0.04	0.00

DAILY RAINFALL AT RIVAS FOR 1898.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
11.....	0.12	0.00	0.00	0.00	0.11	0.00	0.00	0.20	0.80	0.43	1.23	0.00
12.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	1.77	0.00
13.....	0.00	0.00	0.00	0.00	0.00	0.16	0.00	1.71	0.00	0.00	0.69	0.00
14.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.26	1.57	0.00	0.00
15.....	0.00	0.00	0.00	0.00	0.60	0.08	0.00	0.08	1.77	1.65	0.37	0.00
16.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	2.56	0.33	0.08
17.....	0.15	0.00	0.00	0.00	0.00	1.16	1.18	0.00	0.59	0.00	0.00	0.06
18.....	0.00	0.00	0.00	0.00	0.20	3.98	0.86	0.00	0.00	0.30	0.00	0.00
19.....	0.00	0.12	0.00	0.00	3.15	1.26	0.18	0.00	0.37	0.89	0.13	0.00
20.....	0.00	0.00	0.00	0.00	1.30	1.67	0.00	0.00	2.16	1.22	0.00	0.00
21.....	0.00	0.00	0.00	0.00	0.00	0.00	0.80	3.15	0.87	1.75	0.00	0.00
22.....	0.00	0.00	0.00	0.00	2.33	3.22	0.00	0.40	0.43	1.78	0.00	0.00
23.....	0.00	0.00	0.00	0.00	4.57	0.40	0.40	0.60	0.30	0.00	0.00	0.00
24.....	0.18	0.00	0.00	0.00	0.79	0.40	0.00	0.04	0.00	0.12	0.00	0.00
25.....	0.00	0.00	0.06	T.	0.90	0.30	0.20	0.37	0.00	0.47	0.00	0.00
26.....	0.62	0.00	0.00	0.00	0.20	0.00	0.00	0.00	1.26	0.00	0.00	0.00
27.....	0.00	0.00	0.00	0.00	1.07	4.72	0.40	0.00	0.90	0.00	0.36	0.23
28.....	0.00	0.00	0.00	0.00	0 00	1.18	0.00	0.40	0.09	0.98	0.31	2.15
29.....	0.00	0.00	0.00	0.00	0.79	0.00	0.00	1.77	0.00	0.00	0.00	0.00
30.....	0.00	0.00	0.00	0.00	0.00	0.00	3.86	0.00	0.00	0.79	0.00	0.10
31.....	0.00	....	0.00	....	0.00	....	0.00	0.00	....	0.00	....	0.25
Totals..	1.07	0.12	0.10	0.00	16.17	18.95	13.65	11.85	13.99	20.83	8.19	3.14

DAILY RAINFALL AT THE MOUTH OF RIO LAS LAJAS AT CAMP CALDERA NEAR RIVAS, NICARAGUA.

Day.	Jan. 1898.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
1		.00	.00	.00	.00	.00	0.33	.00	0.01	0.15	.00	0.03	.01	.00	.00
2		.00	0.04	.00	.00	.00	1.23	.00	.00	.05	.00	0.09	.00	.00	.00
3		.00	.00	.00	.00	.00	0.24	.00	.00	1.17	.00	.00	.10	.00	.00
4		.00	.00	.00	.00	.00	.00	0.37	0.27	.01	0.17	.00	.02	.00	.00
5		.00	.00	0.12	.00	0.33	.00	.00	.00	.43	.00	.00	.03	.00	.00
6		.00	.00	0.02	0.08	.00	.00	1.40	0.08	.00	.00	.00	.00	.00	.00
7		.00	0.01	.00	.00	0.74	0.26	0.11	0.01	.96	0.12	.00	.00	.00	.03
8		.00	.00	.00	.00	0.09	.00	0.21	0.04	.93	0.07	.00	.00	.00	.00
9		0.05	.00	.00	.00	0.08	0.16	.00	0.05	1.07	1.20	0.18	.00	.06	.00
10		.00	.00	.00	.00	0.40	0.85	.00	0.46	.53	0.06	.00	.00	.00	.00
11		.00	.00	.00	0.06	0.02	0.33	.00	0.03	.12	0.01	.00	.13	.00	.00
12		.00	.00	0.05	.00	0.05	.00	0.05	0.02	.00	0.90	.00	.03	.00	.00
13		.00	.00	.00	.00	0.01	0.07	0.04	1.06	.29	1.07	0.01	.05	.00	.00
14		.00	.00	.00	.00	.00	0.02	0.41	0.62	1.01	.00	.00	.00	.00	.00
15		.00	0.08	.00	0.03	.00	0.03	.00	0.10	1.74	.00	.00	.15	.00	.00
16		.00	0.04	.00	0.16	.00	0.30	0.01	.00	2.49	0.15	0.01	.00	.00	.00
17		.00	.00	.00	.00	0.84	0.67	0.13	.00	.04	0.05	.00	.00	.30	.00
18		.00	.00	.00	0.03	0.22	0.62	0.03	.00	.64	.00	0.01	.00	.00	.00
19		.00	.00	.00	0.58	0.43	0.26	.00	0.09	.20	0.06	00	.00	.25	.00
20		.00	.00	.00	0.66	0.51	0.06	0.01	0.04	.59	0.10	.00	.00	.05	.00

DAILY RAINFALL AT THE MOUTH OF RIO LAS LAJAS AT CAMP CALDERA NEAR RIVAS, NICARAGUA.—Continued.

Day.	Jan. 1898.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
21	....	.00	.00	0.05	0.02	1.40	0.33	3.61	2.47	1.03	.00	.00	.00	.00	.00
22	.....	.00	.00	.00	3.99	2.04	0.21	0.07	0.04	.18	.00	0.13	.00	.00	.00
23	....	.00	0.02	.00	1.44	0.06	0.40	0.01	0.03	.02		.00	.01	.00	.00
24	....	.00	1.11	.00	1.89	0.85	0.29	.00	0.10	.00		.00	.00	.00	.00
25	....	.00	.00	.00	0.19	0.03	0.06	0.15	0.03	1.08	0.20	.00	.00	.00	.00
26	0.06	.00	.01	0.03	0.67	0.97	0.13	0.10	0.19	0.00		.00	.00	.00	.00
27	.00	.00	.00	.00	0.06	3.22	0.07	0.48	0.19	0.11	0.06	0.10	.00	.00	.00
28	.00	.00	.00	0.01	.00	1.09	0.54	.00	0.86	1.34	0.18	1.32	.00	.01	.00
29	.00	....	.00	.00	0.02	0.10	.00	1.07	.00	0.01	.00	0.12	.00	..	.00
30	....	....	.00	.00	0.70	0.02	3.18	0.13	.00	0.00	0.01	0.04	.00	....	.00
31	.00	....	0.03	....	0.02	....	.00	0.05	....	0.00	....	0.22	.00	....	.30
Totals	.06	.05	1.34	.28	10.60	13.50	10.64	8.44	6.79	16.19	4.41	2.26	0.53	0.67	.33

DAILY RAINFALL AT PASO REAL DEL RIO VIEJO.

Day.	Feb. 1898.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.
1.....	.00	.00	.00	.00	.00	.00	.83	.00	.00	.00	.00	.00
2.....	.00	.00	.00	.00	.00	.16	.18	.00	1.03	.00	.00	.00
3.....	.00	.42	.00	.00	.00	.00	.00	.22	.21	.00	.00	.03
4.....	.00	.22	.00	.00	.00	.00	.06	.00	.02	.02	.16	.00
5.....	.00	.00	.00	.00	.00	.00	.60	.16	.01	.00	.00	.00
6.....	.00	.00	T.	.00	.00	.31	.02	.50	.43	.01	.00	.01
7.....	.00	.00	.00	.00	1.25	.18	.00	.01	.36	.00	.00	.00
8.....	.00	.00	.00	.00	.14	.00	.00	.00	.77	.06	.00	.00
9.....	.00	.00	.00	.00	.00	.30	.00	.00	.02	.13	.00	.00
10.....	.00	.00	.00	.00	.30	.70	.00	.40	.00	.01	.00	.00
11.....	.00	.00	.00	.00	.71	.70	.41	.33	.19	.03	.00	.00
12.....	.00	.00	.00	.00	.05	.37	.11	.00	.37	.33	.00	.00
13.....	T.	.00	T.	.00	.00	.00	.81	1.40	.30	.02	.00	.00
14.....	.00	.00	.00	.00	.00	.05	1.16	.00	.54	.00	.00	.00
15.....	.00	.00	.00	.00	.00	.13	1.08	1.70	.02	.00	.00	.00
16.....	.00	.00	.00	.00	.00	.00	.28	.00	.17	.00	.00	.00
17.....	.00	.00	.00	.00	.00	.00	.50	.00	.00	.00	.00	.00
18.....	.00	.00	.00	.87	3.68	.00	.50	.00	2.21	.00	.0	.00
19.....	.00	.00	.00	2.42	.63	.00	.50	1.35	.83	.00	.00	.00
20.....	.00	.01	.00	.71	1.00	.12	.50	.41	.87	.00	.00	.00
21.....	.00	.00	.00	2.51	1.90	.00	.50	.02	.08	.00	.00	.00
22.....	T.	.01	.00	2.83	.52	.00	.36	.07	.07	.00	.01	.00
23.....	.01	.00	.00	1.65	.19	.03	.00	.10	.02	T.	.00	...
24.....	.00	.00	.00	1.91	.32	.00	.00	.00	.00	.00	.00	...
25.....	.00	.00	.00	.47	.12	.00	.00	.00	.01	.00	.00	...
26.....	.00	.00	.00	.05	.00	.00	.08	.26	.29	.00	.00	...
27.....	.00	.00	.00	.35	.08	.02	.01	.29	.00	.00	.00	...
28.....	.00	.00	.00	.00	2.56	.62	2.78	.01	.00	.00	.00	...
29.....	...	.00	.00	.00	.00	.02	.32	.00	.16	.00	.00	. .
30.....	...	.00	.00	.00	.00	.28	.07	.05	.01	.00	.00	...
31.....	...	.00	...	.01	...	.02	.00	...	.00	...	.00	...
Totals..	.01	.66	.00	13.78	13.45	4.01	11.66	7.28	8.99	.61	.17	0.4

NICARAGUA CANAL COMMISSION

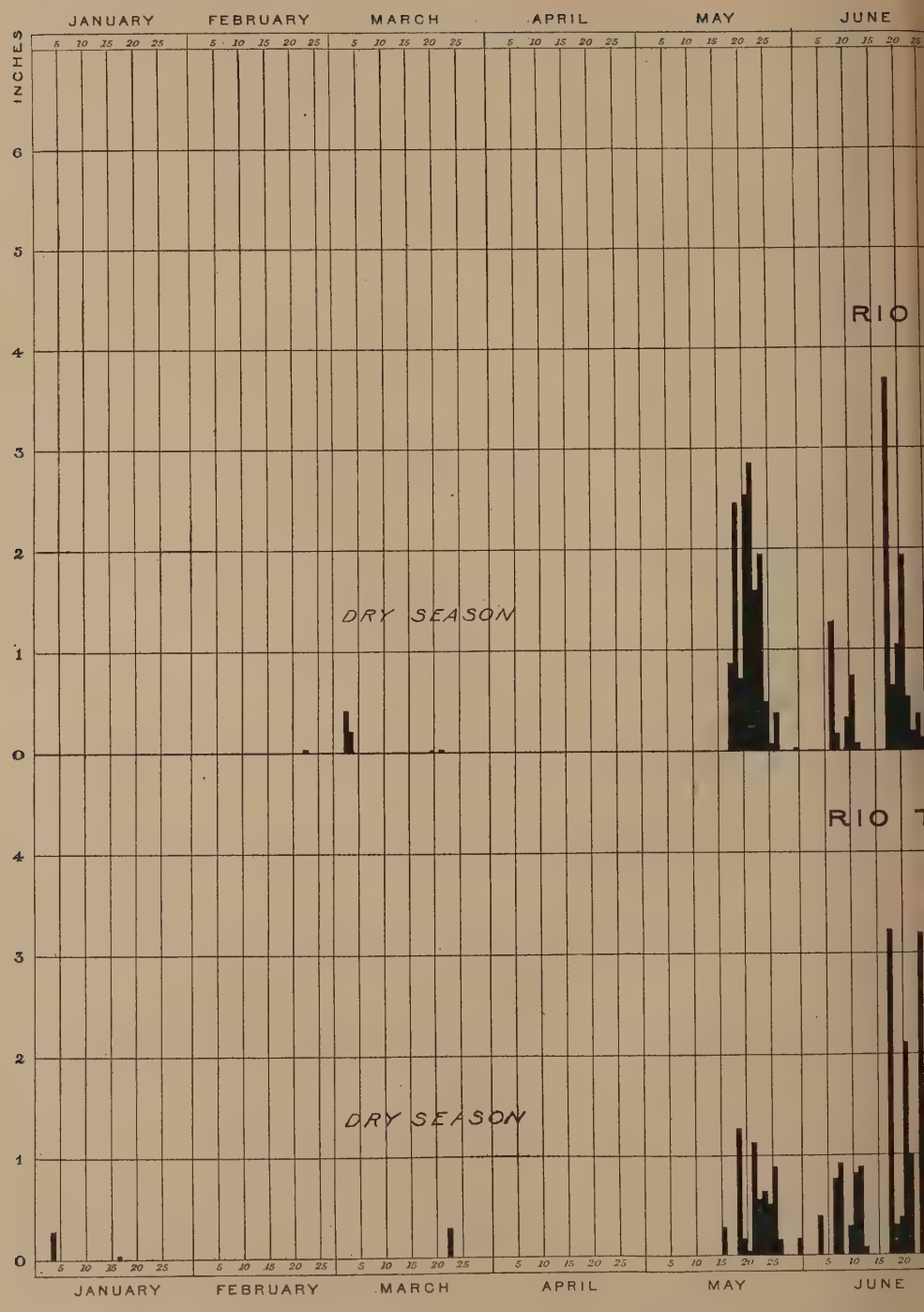
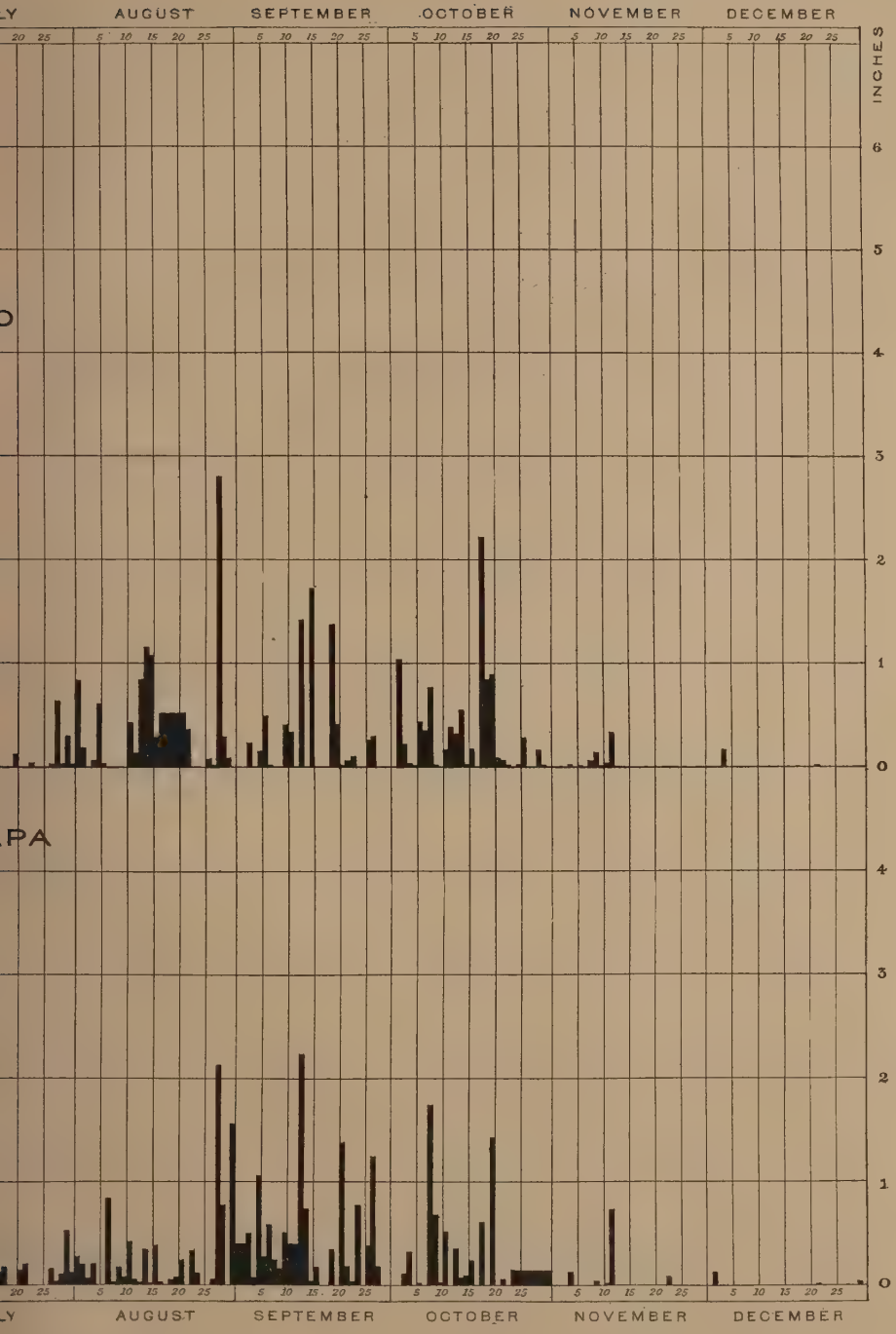


DIAGRAM OF THE DAILY RAINF



ITAPA AND RIO VIEJO, 1898.

DAILY RAINFALL AT TIPITAPA.

Day.	Feb. 1898.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.
1.....	.00	.00	.00	.00	.00	.80	.22	.37	.00	.00	.00	T.
2.....	.00	.00	.00	.00	.00	.26	.16	.37	.00	.00	.12	.00
3.....	.00	.00	.00	.00	.00	.00	.04	.45	.10	.00	T.	.00
4.....	.00	.00	.00	.00	.31	.00	.18	.05	.30	.11	.00	.25
5.....	.00	.00	T.	.00	.00	.00	.00	1.03	.00	.00	.00	.00
6.....	.00	.00	.00	.00	.00	.08	.00	.25	.02	.00	.00	.00
7.....	.00	.00	.00	.00	.73	.00	.81	.56	.00	.00	T.	T.
8.....	.00	.00	.00	.00	.90	.00	.01	.21	1.72	.00	.00	.00
9.....	.00	.00	.00	.00	T.	3.30	.14	.15	.68	.03	.00	T.
10.....	.00	.00	.00	.00	.26	.19	.06	.48	.02	.00	.00	.00
11.....	.00	.00	.00	T.	.78	.20	.40	.37	.52	.01	.00	.00
12.....	.00	.00	.00	.00	.81	.00	.02	.37	.00	.71	.00	.00
13.....	.00	.00	.00	.00	.04	.00	.01	2.21	.34	.00	.00	.00
14.....	.00	.00	.00	.00	.00	.00	.32	.71	.07	.00	.00	.00
15.....	.00	.00	.00	.00	.00	.00	.00	.02	.09	.00	.00	.00
16.....	.00	.00	.00	.22	.00	.00	.35	.14	.21	.00	.00	.00
17.....	.00	.00	.00	.00	.00	.10	.01	.00	.00	.00	.00	.01
18.....	.00	.00	.00	3.10	3.19	.14	.00	.00	.60	.00	.02	.00
19.....	.00	.00	.00	1.22	.22	.00	.03	.30	.00	.00	.00	.00
20.....	.00	.00	.00	.12	.32	.00	.04	.01	1.40	T.	.00	.00
21.....	.00	.00	.00	.04	2.03	.14	.21	1.36	.00	.00	.00	.00
22.....	T.	.00	.00	1.08	.96	.18	T.	.15	.04	T.	.00	.00
23.....	.00	.26	.00	.52	.00	.00	.31	01.	.00	.07	.00	.00
24.....	.00	.00	.00	.60	3.17	.00	.09	T.		.00	.00	..
25.....	.00	.00	.00	.52	.24	.00	.00	.00		.00	.00	..
26.....	.00	.00	.00	.89	.00	.00	.00	.35		.00	.00	..
27.....	.00	.00	.00	.12	.36	.12	.03	1.20	1.01	.00	.00	..
28.....	.00	.00	.00	.00	2.29	.02	2.10	.13		.00	.00	..
29.....	..	.00	.00	.00	.00	.07	.75	.00		.00	.00	..
30.....	..	.00	.00	.00	.27	.54	.00	.00		.00	.03	..
31.....	..	.00	..	.13	..	.10	1.53	..		..	.00	..
Total.....	.00	.26	.00	8.56	16.88	6.24	7.82	11.25	7.12	.93	.17	.26

DAILY RAINFALL AT MORRITO FOR 1898.

Day.	April.	May.	June.	July.	Aug.
1.....	..	.02	.00	.50	.00
2.....	..	.00	.00	1.32	11
3.....	..	.00	.02	.16	.03
4.....	..	.00	1.17	.20	.00
5.....	..	.06	.22	.15	.12
6.....	.01	.00	.00	.38	.08
7.....	.03	.00	.18	.30	.04
8.....	.00	.00	.00	.06	.00
9.....	.00	.39	.67	.24	.62
10.....	.00	.00	.46	.19	.00

DAILY RAINFALL AT MORRITO FOR 1898.—Continued.

Day.	April.	May.	June.	July.	Aug.
11.....	.00	.03	.98	.20	.08
12.....	.00	.00	.05	.00	.00
13.....	.00	.00	.00	.00	2.95
14.....	.00	.00	.17	.86	.00
15.....	.00	.81	.00	.11	.05
16.....	.00	.06	.05	.72	1.03
17.....	.02	.00	.00	.24	.00
18.....	.00	.39	1.53	.20	.30
19.....	.00	.03	1.58	3.14	.04
20.....	.00	.05	.70	.21	0.71
21.....	.00	.36	1.38	.02	.12
22.....	.00	1.58	1.85	.36	.00
23.....	.00	1.84	.02	.60	.41
24.....	.00	2.05	.22	.38	.00
25.....	.00	.00	.16	.70	.58
26.....	.01	.00	.53	.35	1.24
27.....	.00	.20	.53	.27	1.17
28.....	.00	.00	.87	.17	.07
29.....	.00	.46	.12	.00	.37
30.....	.00	.08	.59	1.77	.08
31.....	....	.51	....	.04	.00
Totals..	.07	8.92	14.05	13.84	10.20

DAILY RAINFALL AT FORT SAN CARLOS.

Day.	Mar. 1898.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.	Apr.
1.....	..	.00	.51	.01	.42	.19	.07	.00	.04	.90	.35	.00	.06	.00
2.....	..	.00	.13	.00	.61	.32	.79	.11	.00	.22	.00	.15	.00	.00
3.....	..	.05	.00	.02	1.66	.18	.09	.01	.00	.12	{.74}	.00	.06	.00
4.....		.05	.02	.00	.57	.00	.05	.48	.65	.10		.10	.00	.00
5.....	..	.59	.06	.02	.06	.67	.18	.00	.21	.04	.17	.00	.00	.02
6.....	..	.31	.08	.00	.91	.58	.07	.11	.00	.31	.00	.24	.12	.32
7.....	..	.30	T	.35	.07	.13	.31	.00	.00	.18	.03	.00	.04	.04
8.....	.22	.00	T	.00	.62	.07	.41	1.23	.69	.04	.06	.00	.21	.09
9.....	.00	.01	.38	.26	1.05	.97	.11	.04	.27	.19	.38	.00	.00	.29
10.....	.01	.00	.33	.44	.00	.47	.03	.02	.53	.17	.17	.00	.00	.40
11.....	.00	.44	1.00	.00	.64	.13	3.64	.02	.67	.10	.05	.00	.00	.22
12.....	.00	.15	.00	.01	.65	.08	.68	.05	{1.25}	.07	.47	.54	.04	.10
13.....	.00	.00	.00	1.56	.00	1.30	.22	1.57		.08	.05	.08	.00	.00
14.....	.00	.00	.00	.18	.33	.08	2.21	.10	.39	.00	{.58}	.00	.00	.00
15.....	.00	.00	.19	.02	.12	.00	.00	.71	.35	.00		.13	.10	.00
16.....	.00	.00	.02	.02	.00	.07	.12	.00	1.05	.56	{.53}	.11	.00	.00
17.....	.00	.25	.33	.00	.32	.01	.12	.60	.91	.44		.59	.00	.00
18.....	.00	.00	3.05	1.96	.18	.00	.17	1.07	.11	.02	.26	.08	.00	.00
19.....	.00	.00	.26	1.02	.57	.57	.04	.18	.00	.00	.05	.32	.00	.00
20.....	.22	.01	.37	1.66	.97	.04	.84	.11	.20	.00	.00	.00	.00	.00

DAILY RAINFALL AT FORT SAN CARLOS.—Continued.

Day.	Mar. 1898.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.	Apr.
21.....	.10	.03	.16	3.35	.74	.03	.08	.04	.08	.05	.22	.05	.00	.00
22.....	.06	.02	.25	.67	.39	.02	.05	.04	.05	.05	.08	.00	.00	.00
23.....	.04	.30	.34	.03	.27	.67	.19	.00	.00	.00	.05	.05	.00	.00
24.....	.21	.00	.19	.14	.44	.05	.00	.80	.00	.00	.25	.00	.00	.00
25.....	.19	.00	.02	1.36	.27	.04	.00	.50	.97	.00	.05	.00	.00	.00
26.....	.00	.43	.00	.58	.99	.14	.04	.73	.90	.07	.10	.12	.00	.00
27.....	.00	.06	.00	.38	.09	.35	.05	.26	23	.03	.05	.25	.00	.00
28.....	.00	.00	.04	.72	.29	.03	.00	.15	.27	.89	.00	.00	.00	.00
29.....	.03	.00	.33	.57	.02	.06	.00	.00	.04	.24	.10	..	.00	.00
30.....	.00	00	.10	.23	.04	.02	.00	.00	.00	.31	.00	..	.00	.00
31.....	.13	..	.06	..	.06	.73	..	00	..	.44	.20	..	.42	.00
Totals.	1.21	3.00	8.22	15.56	13.35	8.00	10.56	8.93	9.86	5.62	4.99	2.79	1.05.	1.48

MEAN OF DAILY RAINFALL AT FORT SAN CARLOS (March 8 to December 31), MORRITO (April 6 to August 31), TIPITAPA (February 1 to December 31), RIO VIEJO (February 1 to December 31), LAS LAJAS (February 1 to December 31), 1898.

Day.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.....	.00	.00	.00	.11	.00	.41	.25	.11	.04	.01	.23
2.....	.00	.01	.00	.03	.00	.72	.15	.29	.30	.00	.11
3.....	.00	.14	.01	.00	.01	.41	.05	.19	.38	.00	.03
4.....	.00	.07	.01	.00	.30	.15	.12	.09	.20	.24	.06
5.....	.00	.00	.18	.02	.11	.04	.28	.34	.11	.05	.01
6.....	.00	.00	.07	.03	.00	.34	.42	.22	.14	.00	.08
7.....	.00	.00	.07	.00	.65	.16	.24	.22	.33	.03	.05
8.....	.00	.06	.00	.00	.24	.14	.06	.16	1.16	.21	.01
9.....	.02	.00	.00	.15	.20	1.01	.35	.08	.45	.41	.09
10.....	.00	.00	.00	.07	.37	.39	.11	.34	.14	.15	.04
11.....	.00	.00	.09	.22	.50	.41	.20	1.09	.21	.18	.03
12.....	.00	.00	.04	.00	.19	.20	.05	.27	.11	.64	.02
13.....	.00	.00	.00	.00	.32	.01	1.02	1.22	.62	.43	.02
14.....	.00	.00	.00	.00	.07	.25	.39	.88	.43	.10	.00
15.....	.00	.02	.00	.21	.00	.08	.23	.46	.64	.09	.00
16.....	.00	.01	.00	.09	.01	.20	.35	.06	.72	.30	.14
17.....	.00	.00	.05	.07	.17	.27	.13	.03	.16	.24	.11
18.....	.00	.00	.00	1.49	2.12	.23	.17	.04	1.13	.03	.01
19.....	.00	.00	.00	.90	.78	.79	.23	.45	.30	.02	.00
20.....	.00	.06	.00	.38	.84	.27	.26	.32	.74	.08	.00
21.....	.00	.02	.02	.62	2.01	.25	.89	.98	.29	.02	.01
22.....	.00	.02	.00	1.95	1.21	.23	.09	.08	.08	.01	.05
23.....	.00	.08	.06	1.16	.06	.26	.28	.08	.01	.03	.00
24.....	.00	.33	.00	1.33	.94	.22	.03	.02	.23	.01	.00
25.....	.00	.05	.00	.24	.38	.21	.15	.01	.43	.26	.00
26.....	.00	.00	.09	.32	.42	.29	.31	.21	.29	.24	.02
27.....	.00	.00	.01	.15	.91	.11	.41	.43	.12	.07	.03
28.....	.00	.00	.00	.01	1.51	.33	1.00	.25	.40	.11	.55
29.....	...	01	.00	.16	.16	.02	.51	.00	.08	.01	.09
30.....	...	.00	.00	.18	.22	1.16	0.6	...	.03	.00	.10
31.....	...	.04	...	.15	...	.04	.46	...	.03	...	.17
	.02	.92	.70	10.14	14.70	9.60	9.25	8.92	10.30	3.97	2.06

MEAN OF DAILY RAINFALL.—Continued.

At Ft. San Carlos (January 1 to March 31), Las Lajas (January 1 to March 31), Tipitapa (January 1 to January 23), Rio Viejo (January 1 to January 22), Granada (January 24 to March 31), 1899.

Day.	January.	Day.		Day.	February.	Day.		Day.	March.	Day.	
1....	.09	17....	.06	1....	.00	17....	.44	1....	.02	17....	.00
2....	.00	18....	.06	2....	.07	18....	.03	2....	.00	18....	.00
3....	.09	19....	.01	3....	.00	19....	.19	3....	.02	19....	.00
4....	.19	20....	.00	4....	.03	20....	.02	4....	.00	20....	.00
5....	.05	21....	.06	5....	.00	21....	.02	5....	.00	21....	.00
6....	.00	22....	.02	6....	.08	22....	.00	6....	.04	22....	.00
7....	.01	23....	.02	7....	.00	23....	.01	7....	.04	23....	.00
8....	.01	24....	.08	8....	.01	24....	.00	8....	.07	24....	.00
9....	.10	25....	.02	9....	.02	25....	.00	9....	.00	25....	.00
10....	.04	26....	.03	10....	.00	26....	.04	10....	.00	26....	.00
11....	.04	27....	.02	11....	.00	27....	.08	11....	.00	27....	.00
12....	.12	28....	.00	12....	.18	28....	.00	12....	.01	28....	.00
13....	.03	29....	.03	13....	.02			13....	.00	29....	.00
14....	.10	30....	.00	14....	.00			14....	.00	30....	.02
15....	.08	31....	.07	15....	.04			15....	.03	31....	.24
16....	.08			16....	.04			16....	.00		
			1.51				1.32				0.49

ACCUMULATED RAINFALL IN THE BASIN OF LAKE NICARAGUA.

Obtained by taking the mean of the accumulated rainfall at Ft. San Carlos from March 8, 1898, to March 31, 1899; Morrito from April 6, 1898, to August 31, 1898; Tipitapa from February 7, 1898, to January 23, 1899; Rio Viejo from February 1, 1898, to January 22, 1899; Las Lajas from February 1, 1898, to March 31, 1899; Granada from January 24, 1898, to March 31, 1899.

Day.	Feb. 1898.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
1	....	.02	.94	1.75	11.68	26.79	36.23	45.34	54.19	64.46	68.65	70.57	72.12	73.46
2	....	.03	.94	1.78	11.68	27.51	36.38	45.63	54.49	64.46	68.76	70.57	72.19	73.46
3	....	.17	.95	1.78	11.69	27.92	36.43	45.82	54.87	64.46	68.79	70.85	72.19	73.48
4	....	.24	.96	1.80	11.99	28.07	36.55	45.91	55.07	64.70	68.85	70.86	72.22	73.48
5	....	.24	1.14	1.83	12.10	28.11	36.83	46.25	55.18	64.75	68.86	70.91	72.22	73.48
6	....	.24	1.21	1.83	12.10	28.45	37.25	46.47	55.32	64.75	68.94	70.91	72.30	73.52
7	....	.24	1.28	1.83	12.75	28.61	37.49	46.69	55.65	64.78	68.99	70.92	72.30	73.56
8	....	.30	1.28	1.83	12.99	28.75	37.55	46.85	56.81	64.99	69.00	70.93	72.31	73.63
9	.02	.30	1.28	1.98	13.19	29.76	37.90	46.93	57.26	65.40	69.09	71.02	72.33	73.63
10	.02	.30	1.28	2.05	13.56	30.15	38.01	47.27	57.40	65.55	69.13	71.06	72.33	73.63
11	.02	.30	1.37	2.27	14.06	30.56	38.21	48.36	57.61	65.73	69.16	71.11	72.33	73.63
12	.02	.30	1.41	2.27	14.25	30.76	38.26	48.63	57.72	66.37	69.18	71.23	72.51	73.64
13	.02	.30	1.41	2.27	14.57	30.77	39.28	49.85	58.34	66.80	69.20	71.25	72.53	73.64
14	.02	.30	1.41	2.27	14.64	31.02	39.67	50.73	58.77	66.90	69.20	71.25	72.53	73.64
15	.02	.32	1.41	2.48	14.64	31.10	39.90	51.19	59.41	66.99	69.20	71.43	72.57	73.67
16	.02	.33	1.41	2.57	14.65	31.30	40.25	51.25	60.13	67.29	69.34	71.43	72.61	73.67
17	.02	.33	1.46	2.64	14.82	31.57	40.38	51.28	60.29	67.53	69.45	71.49	73.05	73.67
18	.02	.33	1.46	4.13	16.94	31.80	40.55	51.32	61.42	67.56	69.46	71.65	73.08	73.67
19	.02	.33	1.46	5.03	17.72	32.59	40.78	51.77	61.72	67.58	69.46	71.66	73.27	73.67
20	.02	.39	1.46	5.41	18.56	32.86	41.04	52.09	62.46	67.66	69.46	71.66	73.29	73.67
21	.02	.41	1.48	6.03	20.57	33.11	41.95	53.07	62.75	67.68	69.47	71.71	73.31	73.67
22	.02	.43	1.48	7.98	21.78	33.34	42.02	53.15	62.83	67.69	69.52	71.73	73.31	73.67
23	.02	.51	1.54	9.14	21.84	33.60	42.30	53.23	62.84	67.72	69.52	71.75	73.32	73.67
24	.02	.84	1.54	10.47	22.78	33.82	42.33	53.25	63.07	67.73	69.52	71.87	73.32	73.67
25	.02	.89	1.54	10.71	23.16	34.03	42.48	53.26	63.50	67.99	69.52	71.90	73.32	73.67
26	.02	.89	1.63	11.03	23.58	34.32	42.79	53.47	63.79	68.23	69.54	71.95	73.36	73.67
27	.02	.89	1.64	11.18	24.49	34.43	43.20	53.90	63.91	68.30	69.57	71.97	73.44	73.67
28	.02	.89	1.64	11.19	26.00	34.76	44.20	54.15	64.31	68.41	70.12	71.97	73.44	73.67
29	....	.90	1.64	11.35	26.16	34.78	44.71	54.15	64.39	68.42	70.21	72.02	....	73.67
30	....	.90	1.64	11.53	26.38	35.94	44.77	54.15	64.42	68.42	70.31	72.02	....	73.69
31	....	.94	....	11.68	.....	35.98	45.23	....	64.45	....	70.48	72.12	....	73.93

DAILY RAINFALL AT SABALOS ABOVE TORO RAPIDS.

Day.	Feb. 1898.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
1..	..	.00	.13	1.34	.07	1.32	.00	.02	.03	.00	1.75	.76	.02	.22
2..	..	.00	.00	.08	.00	1.78	.95	.02	.58	.00	.06	.12	.06	.00
3..	..	.00	.00	.00	.00	1.68	.42	.10	.52	.03	.09	.32	.00	.06
4..	..	.23	.47	.00	.23	.56	.00	.11	.38	.20	.00	.94	.00	.00
5..	..	.18	2.41	.52	.00	.40	.00	.00	.10	.17	.15	.68	.14	.00
6..	..	.00	.29	.00	.00	.00	1.78	.82	.14	.02	.25	.13	.24	.02
7..	..	.00	.00	.73	.36	.15	.21	1.07	.04	.10	.47	.42	.00	.35
8..	..	.30	.00	.02	.00	.20	.04	.05	.96	.12	.55	.39	.00	.91
9..	..	.00	.00	.00	.50	.86	.95	.33	.09	.40	.48	.71	.04	.16
10..	..	..	.05	.25	1.26	.86	.64	.00	.04	.42	1.30	.82	.00	.03
11..	..	..	.85	3.05	.05	.32	.32	1.52	.02	.12	.01	.17	.08	.07
12..	..	..	.23	.00	.12	1.45	.15	2.61	.90	1.59	.03	1.38	1.54	.08
13..	..	.00	.00	.17	.12	.12	.79	.57	.13	2.74	.12	.22	.01	.14
14..	..	.00	.00	.00	.36	.12	.15	.26	.09	.13	.00	.93	.01	.16
15..	..	.00	.00	.42	.06	.00	.45	.39	.21	.23	.00	.36	.27	.00
16..	..	.01	.00	.00	.05	.78	.01	1.67	.01	2.14	1.56	.33	.11	.00
17..	..	.00	.84	.15	.00	.86	.00	.00	3.18	1.30	1.25	.00	.67	.11
18..	..	.00	.00	1.07	2.32	.31	.07	.00	.67	.04	.14	.33	.08	.00
19..	..	.00	.00	.43	.65	.65	.27	.17	.53	.00	.00	.00	.09	.00
20..	..	.03	.00	.04	.57	2.22	.30	.04	1.40	.19	.00	.09	.03	.00
21..	.09	.03	.00	.31	1.52	1.23	.58	.83	.00	.20	.03	.12	.04	.00
22..	.07	.11	.05	.09	1.76	.48	.19	.22	.10	.03	.12	.27	.00	.04
23..	.77	.28	.27	.35	.43	.00	.57	.33	.11	.00	.00	.05	.00	.00
24..	.00	.64	.00	.00	.62	.42	.32	.00	.22	.16	.00	.20	.62	.00
25..	.68	.18	.00	.25	1.48	.90	.51	.00	.38	.42	.00	.00	.04	.00
26..	.23	.00	.27	.00	1.42	.90	.00	.00	.66	.56	.00	.05	.00	.00
27..	.07	.04	.14	.85	.31	.11	.06	.26	.01	.26	.07	.00	.08	.00
28.	.00	.00	.00	.16	1.11	1.73	.00	.03	.04	.57	.13	.00	.16	.00
29..	..	.07	.00	1.11	1.76	.07	.36	.00	.00	.02	.33	.01	..	.00
30..	..	.00	.01	.00	.00	.27	.87	.00	.25	.01	.87	.00	..	.00
31..	..	.00	..	.30	..	.00	.37	..	.02	..	.34	.02	..	.38
	1.91	2.10	6.00	11.69	17.13	20.69	11.33	11.42	11.81	12.17	10.20	9.82	4.33	2.73

DAILY RAINFALL AT CASTILLO, ON SAN JUAN RIVER.

Day.	1898. June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	1899. Jan.	Feb.	Mar.
1.....	....	1.75	.18	.00	.00	.00	1.38	.55	.13	.36
2.....	....	1.81	.61	.00	1.83	.00	.58	.46	.01	.00
3.....	....	1.45	.18	.00	.00	.00	.02	.40	.05	.07
4.....	....	.12	.35	.00	.00	.14	.00	.76	.20	.02
5.....	....	.77	1.23	.00	.00	.17	.13	1.19	.07	T.
6.....	....	.01	.27	.00	....	.00	.27	.03	.60	.00
7.....	....	.00	.27	.36	....	.00	.39	.30	T.	.00
8.....	....	.18	.13	1.87	.00	.00	.00	.40	.00	.00
9.....	....	1.48	.74	.27	.33	1.36	.80	1.15	.01	.41
10.....	....	.20	.57	.13	.15	.13	1.38	.07	.05	.27

DAILY RAINFALL AT CASTILLO, ON SAN JUAN RIVER.—Continued.

Day.	June. 1898.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
11.....	....	.89	.41	3.78	.00	.07	.27	.55	.05	.00
12.....	....	.05	.84	.08	.00	1.07	.21	1.35	2.00	.01
13.....	.40	.13	.13	.21	.00	3.18	.08	.82	.00	T.
14.....	....	.11	1.15	.09	.00	.02	.00	.59	.01	.19
15.....	....	.13	.80	.28	.00	.06	.03	.17	.21	.00
16.....	....	.27	.13	2.51	.00	2.30	.40	.27	.93	.13
17.....	....	.67	.00	.05	.30	2.29	2.85	.21	.32	.16
18.....	....	.71	.00	.00	.87	.00	.27	.40	.52	.00
19.....	1.25	1.10	.00	.00	.00	.03	.01	.00	.15	.00
20.....	2.13	.89	.86	.11	.35	.10	.00	.21	.03	T.
21.....	.88	1.63	.70	.88	.01	.15	.02	.08	.00	.02
22.....	1.25	.25	.08	4.05	.03	.01	.00	.00	.01	.01
23.....	....	.94	.00	.54	.00	.01	.00	.00	.13	.05
24.....	1.00	.03	.17	.00	.29	.04	.00	.34	.85	.00
25.....	1.14	.21	.67	.00	.40	.51	.00	.00	.00	.03
26.....	.18	.40	.23	1.01	.33	1.01	.00	.00	.01	.00
27.....	.58	.17	.00	.00	.00	.76	.00	.00	.07	T.
28.....	.16	2.26	.37	.00	.02	.59	.00	.00	.06	.00
29.....	1.50	.31	.39	.00	.00	.04	.00	.01	....	.00
30.....	.00	.00	.00	.00	.00	.00	1.94	.01	....	.00
31.....	....	.00	.00	....	.03	....	.54	T.	....	.29
Totals..	10.47	18.92	11.46	16.22	4.64	14.04	11.57	10.32	6.47	2.02

DAILY RAINFALL AT MACHUCA, ON SAN JUAN RIVER.

Day.	July. 1898.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
1.....	...	.37	.00	.00	.00	1.83	.84	.00	.00
2.....	...	.84	.25	2.05	.00	.00	.65	.22	.00
3.....	...	.00	.75	.12	.00	.00	.74	.00	.00
4.....	...	.00	.00	.31	.56	.00	.84	.00	.00
5.....	...	.50	.00	.50	.00	.47	1.74	.00	.00
6.....	...	.00	.12	.25	.00	.00	.00	.00	.00
7.....	...	.56	.00	.00	.12	.75	.25	.00	.00
8.....	...	.62	.00	.00	.00	.00	.87	.00	.87
9.....	...	.22	.43	.37	2.24	.00	.43	.49	.25
10.....	.40	.78	.00	.00	.00	2.52	.25	.00	.00
11.....	.15	.09	1.18	.00	.00	.00	.74	.00	.00
12.....	.12	.25	.00	.40	1.24	.00	2.73	1.86	.00
13.....	.53	.81	1.33	.37	.87	.00	.59	.00	.00
14.....	.12	.09	.09	.00	.00	.00	.71	.00	.00
15.....	.09	1.06	.09	.00	.25	.00	.25	.46	.00
16.....	.06	.00	1.27	.00	2.73	1.03	.65	.19	.22
17.....	.00	.25	.06	.00	1.55	.00	.00	.53	.00
18.....	.59	.00	.09	3.07	.06	.00	.00	.62	.00
19.....	.37	.00	.28	1.24	.00	.00	.00	.12	.00
20.....	1.12	.00	.00	.00	.56	.15	.34	.00	.00

DAILY RAINFALL AT MACHUCA, ON SAN JUAN RIVER.—Continued.

Day.	July 1898.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
21.....	1.15	.87	.75	.00	.06	.00	.00	.00	.00
22.....	.12	00	1.68	.00	.00	.00	.34	.00	.00
23.....	.06	.03	1.33	.06	.00	.00	.00	.00	.00
24.....	.62	.09	.00	.81	.31	.00	.00	.12	.00
25.....	.47	.40	.00	.00	.43	.00	.00	.00	.00
26.....	.09	.25	1.33	.00	1.43	.00	.00	.00	.00
27.....	.00	.00	1.83	.00	.56	.00	.21	.00	.00
28.....	.12	.00	.00	.03	2.18	..	.00	.00	.00
29.....	.28	.09	.00	.00	.50	..	.00	..	.00
30.....	.06	.00	.00	.25	.00	..	.00	..	.00
31.....	.00	.34	..	.00	..	..	..	..	.31
Totals..	6.52	8.51	12.86	9.83	15.65	6.75	13.17	4.61	1.65

DAILY RAINFALL ON SAN CARLOS RIVER, 1898.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
1.....	..	.04	.10	1.11	1.17	1.28	.33
2.....	..	Trace	.04	.02	.01	1.76	2.59
3.....	..	.00	.02	.16	.00	1.13	.02
4.....	..	.70	.76	1.73	.00	.94	.07
5.....	..	1.26	3.63	.45	.00	1.20	54
6.....	..	.02	1.80	.05	.08	.01	06
7.....	..	.14	.80	.00	.60	.00	.45
8.....	..	.08	.66	.05	.15	1.11	.61
9.....	..	.80	.00	.42	.00	1.07	.89
10.....	..	.10	.30	.68	.69	1.94	.01
11.....	..	.00	.48	1.53	.17	.22	.34
12.....	..	.10	.34	.03	.01	.04	.51
13.....	..	.00	.04	.11	2.06	.00	1.48
14.....	..	.00	.02	1.23	.32	.09	.21
15.....	..	.00	.00	.87	.23	.00	.20
16.....	.00	.00	.00	.04	.02	.00	.34
17.....	.02	.04	.00	.05	.00	.00	.45
18.....	.15	.09	.28	1.18	.60	1.05	.00
19.....	.00	.00	.39	2.86	1.37	.19	.00
20.....	.22	.24	.00	.56	1.32	1.41	.50
21.....	.00	.71	.02	1.99	.57	.73	.69
22.....	.24	.37	.10	.19	1.95	.00	.00
23.....	.04	.02	.80	.43	2.82	.17	.94
24.....	.38	.36	.49	.00	.64	.74	.00
25.....	.57	.90	.07	.00	1.57	1.09	.00
26.....	1.14	.48	.33	.06	.61	.36	.32
27.....	1.02	.87	.10	.18	1.22	.10	.13
28.....	.85	.08	.00	.26	1.42	.02	.00
29.....	..	.00	.00	.24	1.06	1.59	.00
30.....	..	.08	.00	.42	.13	.02	.00
31.....	..	.00	..	3.23	..	.00	.00
Total...	4.63	7.52	11.66	20.12	20.79	18.26	11.68

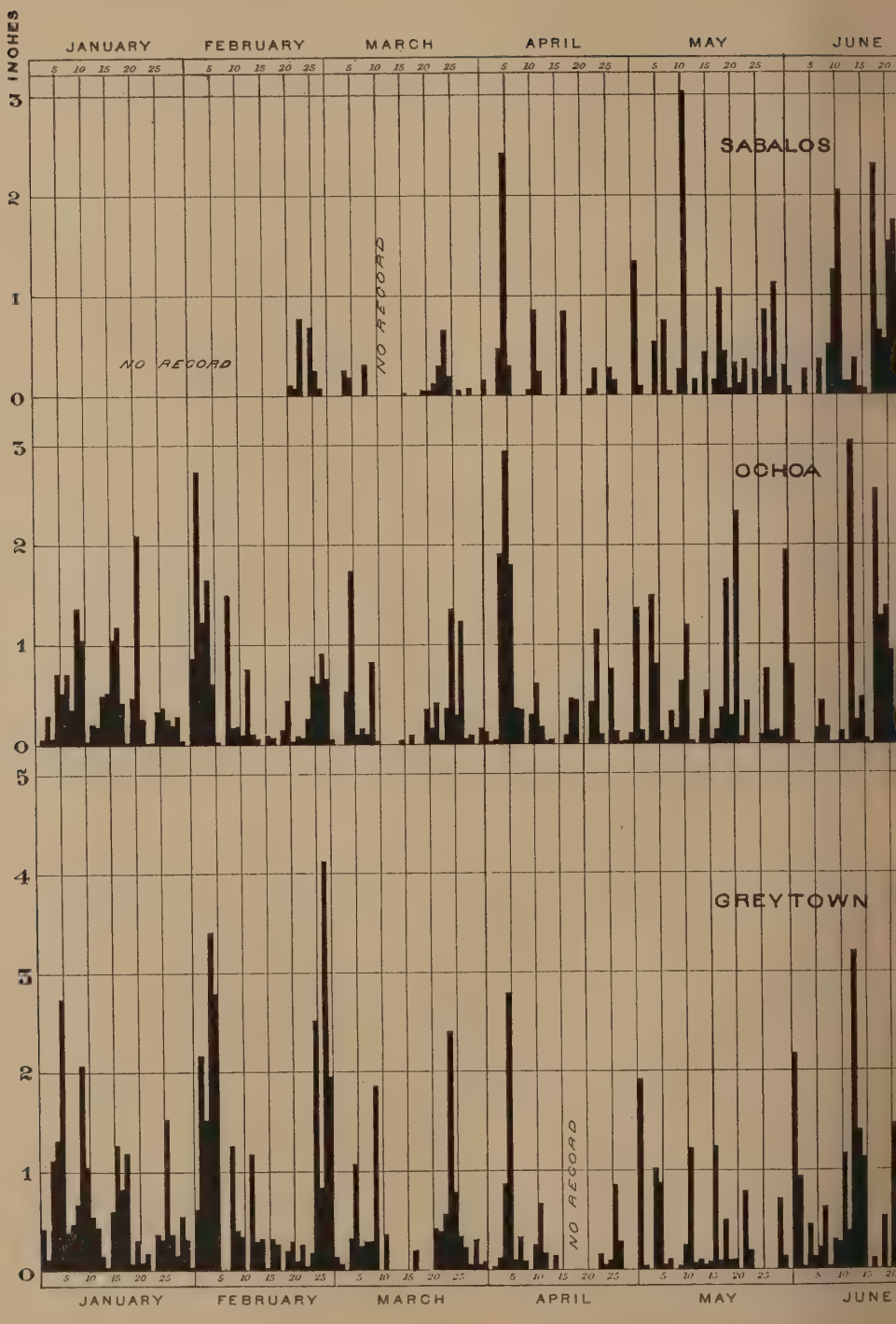
DAILY RAINFALL AT OCHOA, ON SAN JUAN RIVER.

Day.	Jan. 1898.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
1....	.01	.87	.03	.12	1.35	.80	1.07	1.20	.21	1.17	.00	.79	1.17	.37	.25
2....	.05	2.73	.00	.02	.12	.01	2.81	.83	.20	.44	.00	.05	1.83	.11	.01
3....	.28	1.22	.00	.03	.01	.00	.62	.01	.04	.00	.26	.07	.59	.08	.14
4....	.06	1.67	.52	1.91	1.49	.00	1.73	.02	.11	.52	.62	.32	.84	.01	.05
5....	.71	.61	1.75	2.97	.79	.00	.30	.71	.17	.33	.21	.18	1.31	.18	.00
6....	.51	.01	.08	1.80	.12	.15	.01	.04	.14	.23	.52	.63	.05	.22	.02
7....	.72	.00	.17	.35	.01	.42	.01	.29	.14	.00	.26	.15	.67	.00	1.36
8....	.34	1.50	.10	.34	.31	.16	1.03	.54	.12	.01	2.19	.20	.25	.00	2.51
9....	1.37	.17	.82	.00	.14	.01	1.11	.89	.12	.09	.13	.63	.17	.11	.06
10....	1.04	.18	.02	.29	.62	.01	1.68	.01	.00	.03	.33	1.32	.22	.17	.00
11....	.02	.09	.00	.60	1.19	.12	.09	.23	1.76	.05	.07	1.00	.54	.08	.05
12....	.20	.76	.00	.15	.01	.01	.05	.41	1.26	.03	2.16	.04	1.28	.99	.03
13....	.19	.11	.00	.02	.00	3.06	.11	1.74	1.61	.19	.78	.31	.24	.49	.35
14....	.05	.05	.00	.03	.22	.23	.00	.30	.44	.03	.33	.03	.24	.01	.26
15....	.51	00	.03	.00	.52	.48	.07	.03	.00	.08	1.38	.01	1.49	.13	.24
16....	1.05	.09	.00	.00	.03	.03	.02	.07	.06	.14	5.10	.22	.80	.58	.09
17....	1.18	.07	.09	.07	.13	.01	.17	.35	.01	.09	2.17	.57	.01	.33	.09
18....	.42	.00	.00	.47	.36	2.58	.64	.01	.86	.92	.27	.09	.43	.95	.01
19....	.02	.15	.00	.43	1.66	1.29	.19	.01	.14	.11	.02	.01	.16	1.45	.00
20....	.47	.44	.35	.00	.27	1.38	1.84	.03	.00	.00	.07	.08	.22	.27	.00
21....	2.12	.01	.15	.00	2.34	.93	1.21	1.18	1.34	.88	.14	.01	.54	.33	.02
22....	.26	.14	.41	.42	.06	.33	.01	.01	2.25	.15	.01	.00	.44	.09	.00
23....	.01	.07	.02	1.15	.42	2.36	1.00	2.01	.54	1.55	.03	.02	.04	.16	.00
24....	.02	.26	.36	.07	.00	1.12	.59	.29	.00	.09	.34	.00	.34	.06	.00
25....	.35	.69	1.35	.00	.00	2.70	1.62	.05	.23	.39	.49	.00	.03	.05	.00
26....	.36	.61	.30	.75	.08	.56	2.43	.28	2.01	.23	1.11	.73	.04	.06	.00
27....	.23	.92	1.21	.11	.76	.57	.02	.06	.10	.08	.83	.11	.01	.33	.01
28....	.20	.66	.05	.01	.11	.32	.07	.00	.00	.00	.94	.00	.00	.35	.02
29....	.29	....	.08	.02	.12	1.73	1.04	.04	.03	.00	.72	.24	.02	....	.00
30....	.03	....	.00	.10	.05	.10	.06	.15	1.23	.15	.02	.40	.00	....	.01
31....	.00	....	.15	....	1.96	....	.00	.29	....	.04	....	.17	.05	....	.22
	13.07	14.08	8.04	12.23	15.25	21.47	21.60	12.08	15.12	8.02	21.50	8.38	14.02	7.96	5.80

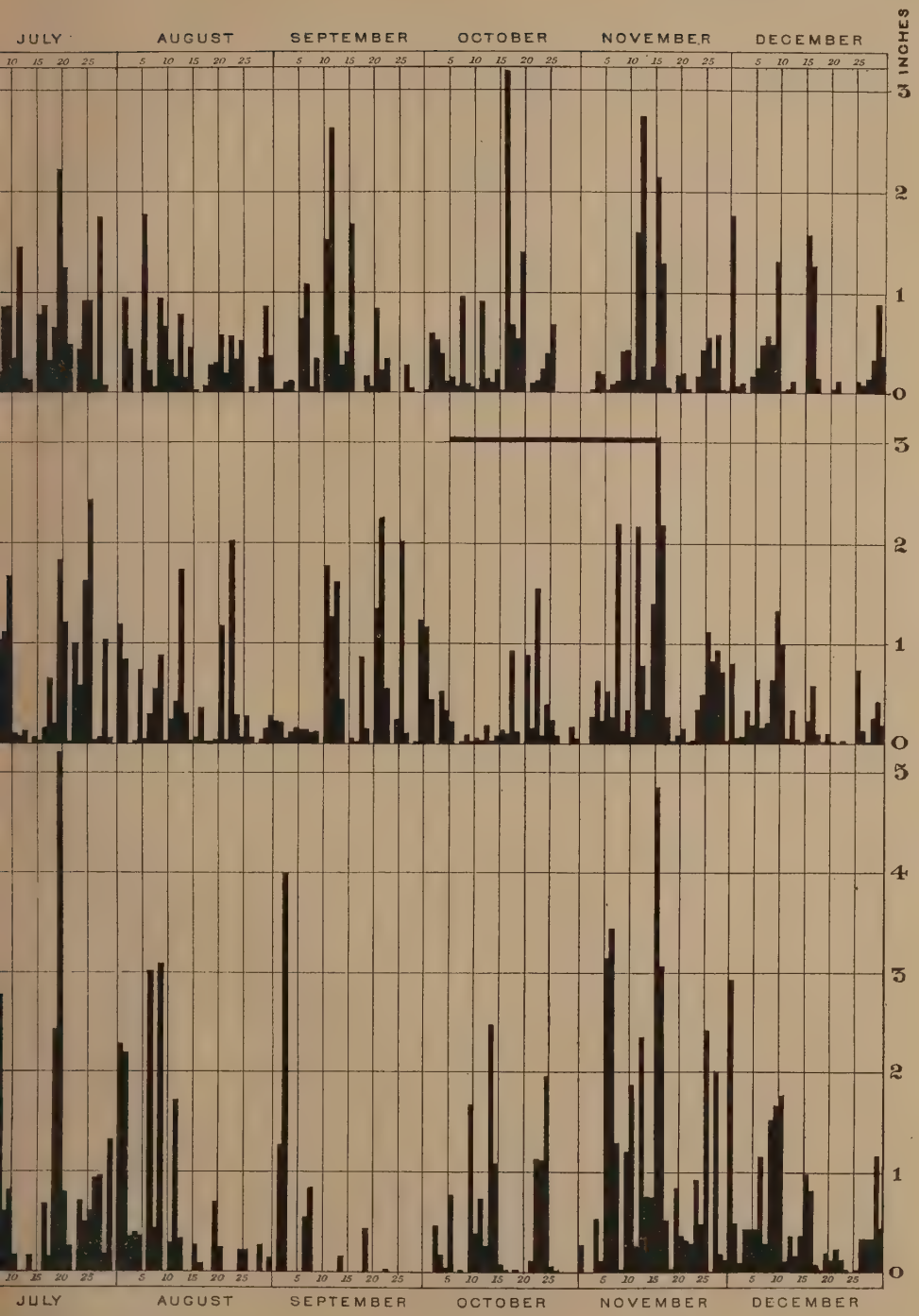
DAILY RAINFALL AT STATION ON THE RIO SAN FRANCISCO, 1898.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.....	....	1.26	.05	.07	1.94	.58	.82	.97	.16	.15	.00	1.02
2.....	....	3.74	.00	.03	.17	.00	2.84	1.11	.31	.76	.00	.07
3.....	....	1.70	.00	.01	.09	.00	1.06	.01	.30	.09	.00	.10
4.....	....	1.66	.57	1.94	1.22	.00	1.37	.27	.00	.32	.71	.09
5.....	....	1.02	1.54	2.35	.66	.11	.55	.03	.00	.35	07	.34
6	.10	.01	.06	.74	.35	.00	.00	.00	.42	.29	.60	.60
7.....	1.08	.00	.27	.30	.00	.08	.06	1.24	.16	.10	.93	.17
8.....	.28	2.33	.02	.32	.19	.00	.78	.86	.17	.02	4.07	.28
9.....	2.10	.18	1.25	.01	.22	.13	.38	1.02	.18	1.03	.35	.72
10.....	1.03	.28	.03	.25	.46	.08	1.41	.01	.01	.18	.30	2.28
11.....	.05	.17	.00	.89	1.51	.38	.09	1.48	1.07	.09	.04	1.30
12.....	.29	.92	.02	.46	.02	.00	.10	.55	2.19	.40	.82	.00
13.....	.44	.11	.00	.11	.00	2.59	.00	1.40	.61	.57	1.64	.34
14..	.18	.02	.00	.15	.00	.29	.19	.27	.38	.06	.66	.02
15.....	.50	.00	.45	.00	1.26	.45	.08	.09	.17	.05	.78	.16

NICARAGUA CANAL COMMISSION



COMPARATIVE DIAGRAMS OF RAINFA



THREE POINTS ON SAN JUAN RIVER.

DAILY RAINFALL AT STATION ON THE RIO SAN FRANCISCO, 1898.—Continued.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
16.....	1.11	.16	.25	.00	.03	.01	.08	.00	.00	.07	5.26	.32
17.....	1.60	.07	.09	.06	.27	.19	.10	.14	.00	.00	1.55	.42
18.....	1.04	.00	.02	.74	.21	.19	1.13	.00	.27	.47	.23	.16
19.....	.01	.16	.01	.67	.71	3.02	.26	.30	.27	.03	.00	.00
20.....	.31	.28	.18	.01	.37	.17	1.46	.25	T.	.00	.11	.00
21.....	2.07	.06	.27	.00	1.45	.17	1.45	.20	1.74	.88	.07	.00
22.....	.31	.90	.39	.30	.14	1.02	.00	.01	.30	.22	.05	.21
23.....	.00	.03	.02	.96	.45	.39	.57	1.33	1.85	1.58	.09	.10
24.....	.55	.23	.46	.33	.00	3.01	.82	.17	.04	.25	.27	.00
25.....	.31	.40	.87	.00	.00	2.04	2.17	.14	.00	.69	.51	.00
26.....	.70	.86	.24	.26	.19	1.92	.45	.66	.08	.12	.89	.84
27.....	.08	1.17	1.25	.24	.09	.78	.04	.79	.06	.18	.90	.26
28.....	.05	.71	.02	.02	.00	.28	.36	.00	.00	.05	1.38	.00
29.....	.62		.16	.00	.55	.99	.52	.05	.21	.00	.10	...
30.....	.07		.01	.03	.00	.00	.13	.06	.00	.07	.00	...
31.....	T.		.22		1.32		.00	.04		.02		...
Totals..	14.88	18.43	8.72	11.25	13.87	18.87	19.22	13.45	10.95	9.09	22.38	9.80

DAILY RAINFALL ON RIO SARAPIQUI, FIVE MILES ABOVE ITS MOUTH.

Day.	July. 1898.	August.	September.	October.	November.	December.	January. 1899.	February.	March.
1.....	....	.50	.54	.00	.00	.64	.82	.25	.24
2.....	....	2.10	.39	.00	.00	.07	1.17	.01	.08
3.....	....	.10	.04	.03	.00	.07	1.74	.03	.31
4.....	....	.05	.01	.86	.49	.18	1.17	.00	.03
5.....	....	....	.00	.86	.36	1.09	.45	.35	.00
6.....	....	....	.00	.50	1.07	.16	.00	.04	.01
7.....	....	....	.23	.63	1.18	.06	1.15	.00	1.07
8.....	....	....	.11	.02	2.51	.31	.26	.00	1.73
9.....	....	....	.00	.12	.00	.54	.54	.00	.18
10.....	....	....	.18	.25	.14	1.65	.30	.54	.04
11.....	....	....	.75	1.05	.09	.44	.95	.20	.00
12.....	....	....	.00	.68	.36	.02	1.66	1.61	.07
13.....	....	....	2.35	.28	.29	.08	1.05	.72	.53
14.....	....	....	.41	.08	.36	.08	.31	.05	.12
15.....	....	....	.20	.04	.76	.00	1.82	.13	.34
16.....	....	....	.01	.15	2.15	.19	1.09	.09	.13
17.....	....	....	.02	.13	3.75	.41	.07	.22	.07
18.....	....	....	1.45	T.	.95	.06	.56	.76	.16
19.....	....	.00	.04	.35	.01	.00	.06	.66	.01
20.....	....	1.02	.00	.00	.00	.01	.40	.23	.00
21.....	....	.01	2.44	.00	.07	.00	.11	.11	.01
22.....	....	.00	.00	1.79	.00	.16	.07	.03	.00
23.....	....	.19	1.16	2.15	.01	.23	.10	.46	.00
24.....	....	.04	.01	.26	1.35	.00	.59	.36	.18
25.....	....	.00	.00	.84	.16	.00	.05	.00	.00

DAILY RAINFALL ON RIO SARAPIQUI, FIVE MILES ABOVE ITS MOUTH.—Continued.

Day.	July. 1898.	August.	September.	October.	November.	December.	January. 1899.	February.	March.
26.....	.15	.00	.00	.17	.39	.23	.03	.19	.00
27.....	.12	.00	.05	.02	1.05	.07	.04	.65	.00
28.....	.05	.17	.00	.00	.78	.00	.00	.08	.00
29.....	.10	.08	.80	.00	.33	.12	.00	....	.00
30.....	.93	.00	.00	.03	.02	.21	.00	....	.01
31.....	.90	.10	....	.06	....	.08	.01	....	.35
	2.25	4.36	11.19	11.35	18.63	7.16	16.57	7.77	5.67

DAILY RAINFALL OF RIO DESEADO AT CAMP BARTON FOR 1898.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.....	.14	.86	.03	.19	1.78	.76	3.70	2.06	.74	.00	.76	2.75
2.....	.15	4.61	.03	.00	.29	.00	2.48	1.88	.10	.42	.00	.49
3.....	.92	1.70	.00	.07	.01	.00	1.08	.11	.58	.51	.00	.07
4.....	.38	4.37	.26	1.30	1.29	.00	..	.51	.20	.58	.25	.11
5.....	1.23	1.31	1.49	2.33	1.05	.38	..	.21	.07	.09		.11
6.....	.46	.00	.22	.39	.32	.02	..	.00	.15	.63		.67
7.....	1.91	.00	.09	.22	.02	.63	.00	1.77	.20	.00	2.96	.69
8.....	.45	1.82	.63	.19	.04	.00	1.06	.94	.68	.04		.40
9.....	2.66	.21	2.60	.14	.08	.69	1.44	1.84	.00	2.30		1.66
10.....	1.24	.95	.02	.29	.57	.00	.80	.37	.34	1.07	1.11	1.65
11.....	.98	.49	.04	.51	.91	.99	.15	.03	.54	.97	1.02	1.38
12.....	.20	1.13	.03	.10	.06	.03	.02	1.37	.21	.03	.30	.02
13.....	.34	.32	.00	.01	.07	2.48	.02	.28	.81	.28	2.70	.21
14.....	.00	.08	.06	.07	.01	1.22	.07	.29	.07	.30	.53	.00
15.....	1.21	.00	.00	.00	.00	.50	.00	.00	.00	.44	1.83	.23
16.....	1.91	.13	.04	.00	.75	.25	.24	.00	.00	.13	5.30	.91
17.....	1.08	.40	.17	.02	.47	.01	.67	.00	.00	.00	3.61	.45
18.....	.76	.00	.00	.01	.09	.00	.76	.00	.16	.00	.74	.02
19.....	.09	.28	.02	.12	1.44	.99	1.55	.04	.24	.30	.01	.00
20.....	.59	.31	.34	.00	.07	.87	3.83	.03	.00	.00	.85	.00
21.....	1.69	.10	.12	.00	1.22	.34	2.69	.28	.09	.03	.22	.10
22.....	.50	.33	.31	.77	.11	.01	.08	.12	.00	.03	.09	.44
23.....	.03	.63	.29	1.06	.45	2.06	.31	.00	.03	1.37	.08	.01
24.....	.57	.26	1.05	.13	.00	2.10	.18	.00	.00	.56	.85	.00
25.....	.53	1.33	1.75	.00	.00	.92	.77	.37	.02	1.36	.63	
												1897
26.....	.78	1.03	.27	.73	.00	.08	.27	.52	.00	.08	2.30	1.13
27.....	.36	3.04	.98	.17	.05	.28	.90	.01	.00	.00	1.37	2.27
28.....	.18	1.29	.02	.00	.00	.88	86	.00	.00	.30	1.44	1.35
29.....	.30	..	.37	.01	1.01	2.04	.32	.19	.00	.00	.30	1.66
30.....	.25	..	.25	.00	.08	.13	2.02	.00	.00	.10	.00	1.60
31.....	.03	..	.28	..	2.60	..	.00	.09	..	.00	..	.69
Totals	21.92	26.98	11.76	8.83	14.84	18.66	26.27	13.31	5.23	11.92	29.25	21.07

NICARAGUA CANAL COMMISSION

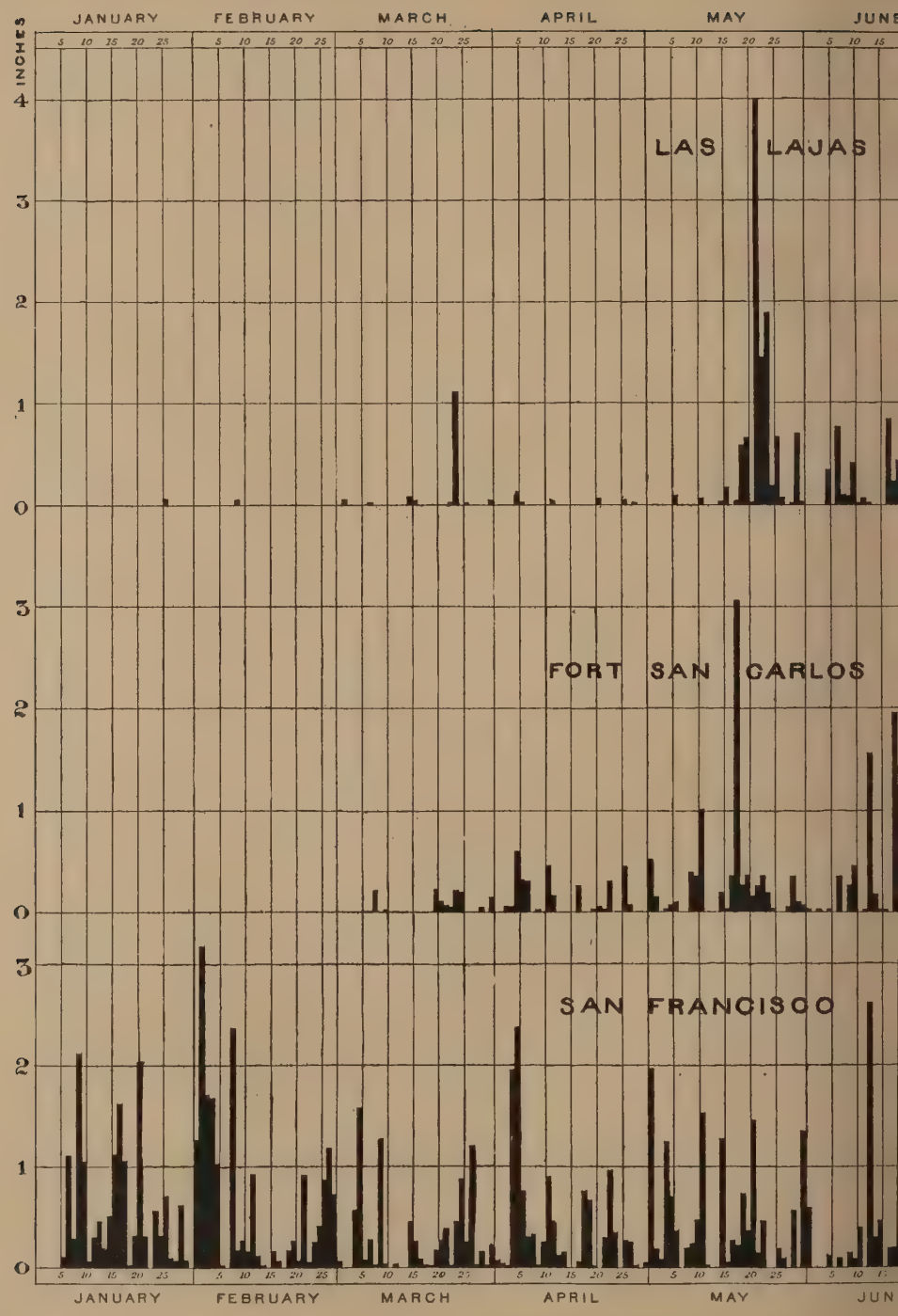
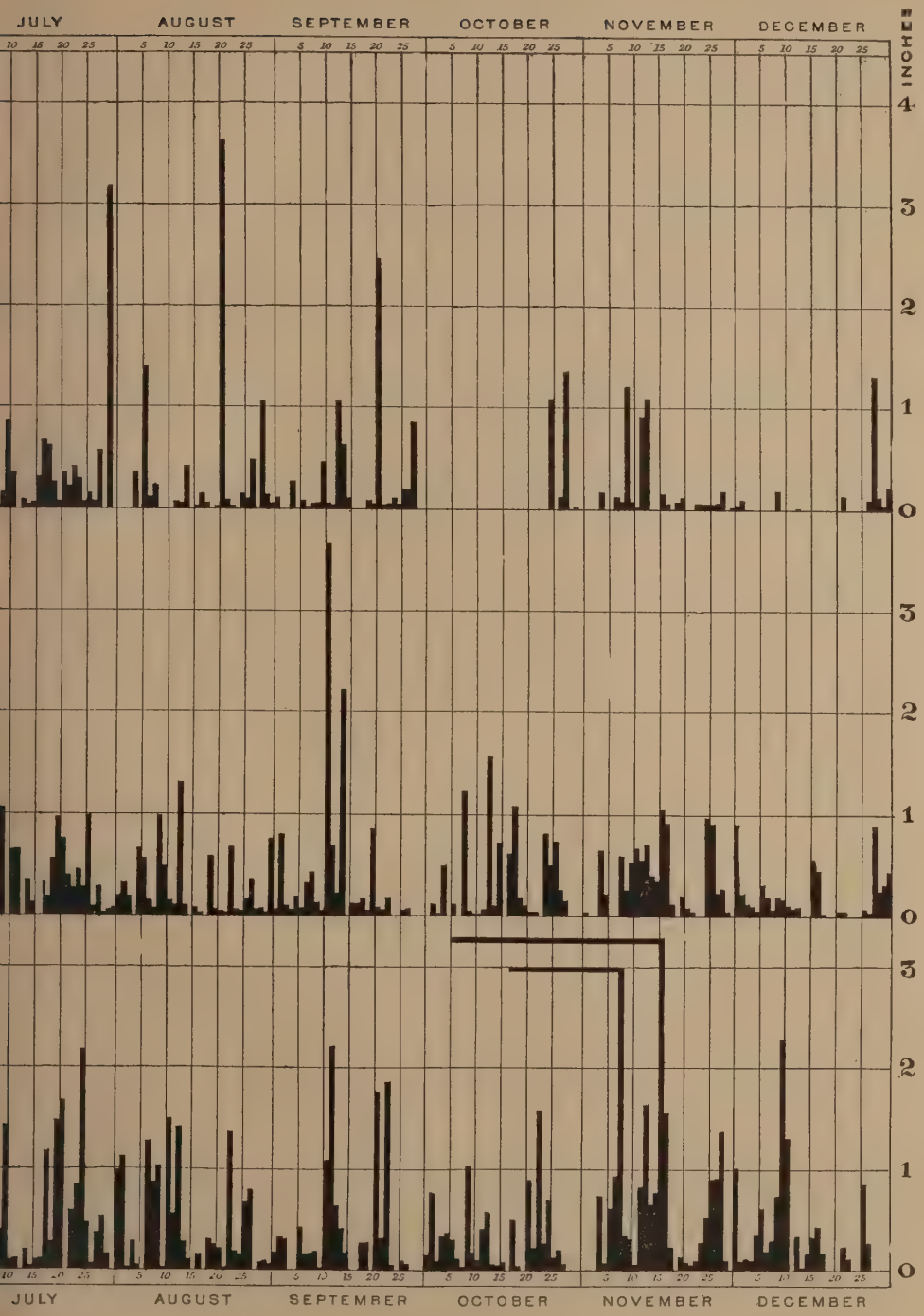


DIAGRAM OF THE DAILY RAINFALL AT LAS



. SAN CARLOS AND RIO SAN FRANCISCO, 1898.

DAILY RAINFALL AT GREYTOWN, NICARAGUA.

Day.	Jan. 1898.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.	Apr.
1....	.42	.61	.13	.00	1.90	2.17	.00	2.28	.00	.00	.27	2.91	1.44	.08	.52	.27
2....	.12	2.16	.05	03	.04	.92	1.43	2.19	1.26	.00	.00	.48	.80	1.00	.00	.03
3....	1.11	1.51	.00	.12	.00	.00	1.51	.35	4.00	.44	.00	.08	.92	....	.03	.28
4 ...	1.32	3.41	.32	.86	1.00	.45	.42	.38	.00	.16	.52	} .82 {	.27	.47	.00	.40
5....	2.72	2.80	1.04	2.79	.85	.11	.00	.35	.00	.03	.10		.50	.25	.00	.30
6....	.39	.00	.22	.10	.04	.21	12	.00	.00	.77	3.14	.41	.59	.02	.00	.12
7....	.45	.00	.27	.33	.09	.62	2.05	3.00	.55	.00	3.43	1.14	1.61	.45	1.00	.00
8....	.67	1.25	.27	.08	.00	.00	2.77	.42	.85	.02	1.30	.29	.67	.00	.45	2.35
9....	2.07	.40	1.84	.00	.02	.29	.60	3.09	.00	.00	.02	1.50	1.17	.00	.00	1.57
10....	1.05	.34	.00	.25	.23	.27	.83	.00	.00	1.68	1.20	1.68	1.91	.02	.03	1.36
11....	.54	.00	.35	.67	1.20	1.14	.15	.28	.00	.39	1.89	1.75	2.08	.30	.01	.48
12....	.43	1.16	.00	.17	.06	.38	.00	1.71	.00	.72	.25	.10	2.46	2.45	.06	1.36
13....	.14	.29	.00	.00	.08	3.20	.00	.32	.00	.26	2.35	.34	.49	.10	1.02	.37
14....	.03	.31	.00	.12	.04	1.40	.14	.00	.15	2.46	.76	.15	.46	.04	.55	.00
15....	.60	.00	.00	.00	.07	1.13	.00	.00	.00	1.09	.75	.35	2.50	1.51	.30	.08
16....	1.26	.30	.00		1.22	.00	.00	.25	.00	.07	4.85	.99	1.32	.45	.05	.00
17....	.81	.26	.18		.08	.10	.67	.06	.00	.01	3.07	.80	.01	1.06	2.19	.00
18....	1.19	.00	.00		.50	.00	.14	.00	.00	.00	.52	.06	2.21	1.23	.03	.00
19....	.06	.19	.00	No Readings.	.08	.52	2.42	.00	.42	.02	.04	.00	.19	.87	.00	.05
20...	.29	.27	.00		.08	.00	5.18	.69	.00	.00	.84	.18	.29	.45	.00	.00
21....	.06	.07	.40		.00	1.46	.79	.23	.00	.00	.37	.11	.49	.13	.00	.02
22....	.18	.24	.38		.78	.00	.26	.00	.00	.10	.31	.22	.19	.00	.00	.00
23....	.00	.03	.54	.15	.19	.29	.00	.00	.01	1.14	.29	.12	.12	.00	.04	.00
24....	.36	.18	2.40	.04	.00	2.75	.70	.00	.00	1.12	.91	.02	.56	.38	.25	.00
25....	.30	2.50	.78	.08	.00	1.24	.49	.20	.00	1.96	.48	.00	.00	.01	.02	.00
26....	1.52	.82	.32	.83	.00	.09	.60	.20	.00	.05	2.41	.02	.11	.00	.09	.05
27....	.36	4.12	.22	.28	.00	.06	.92	.00	.00	.01	....	} .96 {	.00	.23	.08	.00
28....	.13	1.95	.04	.00	.00	.20	.95	.00	.00	.00	2.00		.00	.19	.25	.00
29....	.53	....	.30	.00	.70	.52	.17	.25	.00	.00	.17		.05	....	.00	.00
30....	.30	....	.04	.00	.12	.00	1.32	.00	.00	.00	.11	1.16	.02	....	.00	.00
31....	.03	....	.07	....	.00	....	.00	.13	....	.00	....	.42	.06	....	1.36	....
Totals	19.44	25.17	10.16	6.90	9.37	19.52	24.63	16.38	7.24	12.50	32.35	17.06	23.49	11.69	8.33	9.09

MONTHLY RAINFALL OF NICARAGUA, 1898.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Brito and Tola	.25	.00	.08	.08	11.30	14.86	11.42	6.17	16.60	25.70	6.01	2.41	94.88
Rivas.....	1.07	.13	.10	.00	16.17	18.95	13.65	11.85	13.99	20.83	8.19	3.14	108.06
Las Lajas	.25	.05	1.34	.28	10.60	13.50	10.64	8.44	6.79	16.19	4.41	2.26	74.75
Rio Viejo	....	.01	.66	.00	13.78	13.45	4.01	11.66	7.28	8.99	.61	.17	60.62
Tipitapa.....	....	.00	.26	.00	8.56	16.88	6.24	7.82	11.25	7.12	.93	.17	59.23
Morrito.....	....	....	....	.07	8.92	14.05	13.84	10.20	....	....	....	....	....
Ft. San Carlos.	....	....	1.21	3.00	8.22	15.56	13.35	8.00	10.56	8.93	9.86	5.62	84.31
Sabalos.....	....	....	2.10	6.00	11.69	17.13	20.69	11.33	11.42	11.81	12.17	10.20	114.54
Castillo.....	....	....	....	....	....	....	18.92	11.46	16.22	4.64	14.04	11.64	....
Machuca.....	....	....	....	....	....	....	....	6.52	12.86	9.83	15.65	6.75	....
Rio San Carlos	....	....	7.52	11.66	20.12	20.79	18.26	11.68	....	....	....	....	....
Ochoa.....	13.07	14.08	8.04	12.23	15.25	21.47	21.60	12.08	15.12	8.02	21.50	8.38	170.84
San Francisco*	15.33	18.43	8.72	11.25	13.87	18.87	19.22	13.45	10.95	9.09	22.28	10.61	172.17
Sarapiqui.....	....	....	....	....	....	....	....	....	11.19	11.35	18.63	7.12	....
Deseado†.....	21.92	26.98	11.76	8.83	14.84	18.66	26.86	13.31	5.23	11.92	29.25	21.07	210.63
Greytown	19.44	25.17	10.16	7.82	9.37	19.52	24.63	16.38	7.24	12.50	32.35	17.06	201.64

* Record incomplete from Jan. 1–5 incl., and from Dec. 29–31 incl.; so the rainfall at Ochoa for those days is added.

† Rainfall not observed from Dec. 25 to 31, 1898; so the record was completed by including the corresponding days of 1897.

Miscellaneous Rainfall Records.

Other records of rainfall have been furnished to this Commission through the courtesy of Hon. Willis L. Moore, Chief of the Weather Bureau, as follows:

A record of 19 years at Rivas, beginning January, 1880, kept by Dr. Earl Flint, an American resident.

A record at Masaya from July, 1886, to December, 1896, kept by Mr. Wm. Climie, an English Civil Engineer. In January, 1897, these observations were transferred to Granada and have been continued ever since, although results are at hand only to the end of 1897.

Records of rainfall in Granada in 1876 by Ramon Espinola, in 1877 by Dr. Flint, and in 1883-84 by the National Institute at Granada.

A record at Bluefields by Hon. W. H. Jackson and others, from September, 1883, throughout 1884 and 1885, and a portion of 1886.

A record at Greytown for the years 1890, 1891, 1892, and a portion of 1893 by the Nicaragua Canal Company. These records are given below.

The greatest fluctuation of Lake Nicaragua, which cannot be prevented, and which, therefore, must be provided for, is occasioned by the excess of evaporation, leakage and use over the inflow for limited periods, hence this important factor depends upon the period of least rainfall in the lake basin. On the east side of the isthmus the problems consist chiefly of the control and discharge of excessive floods, and of their effect upon the permanence and stability of the works. For this reason we are most concerned with the year of maximum rainfall in this region. It is a somewhat remarkable fact that the year 1890 is the absolute minimum of the Rivas record, and the maximum in the Greytown record, and may, therefore, be taken as a typical illustration of the problems with which we have to deal. For this reason Map 1, Sheet 3,[1] has

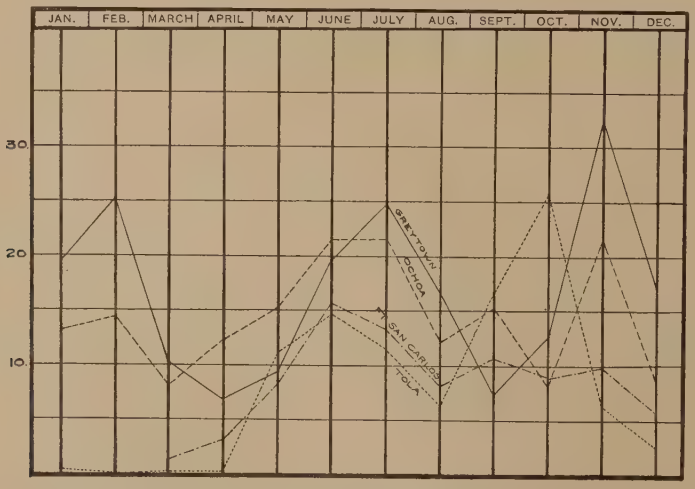
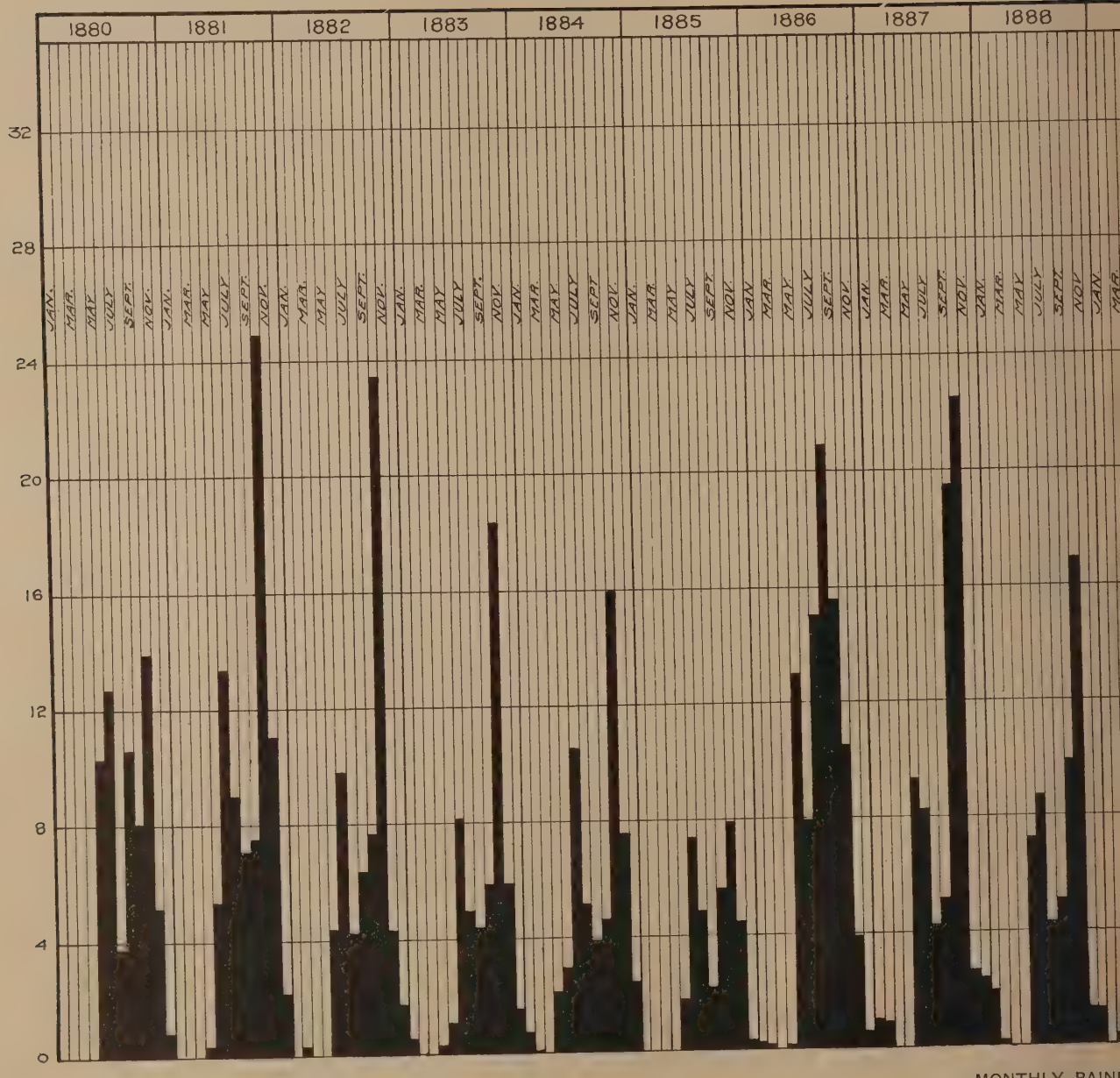


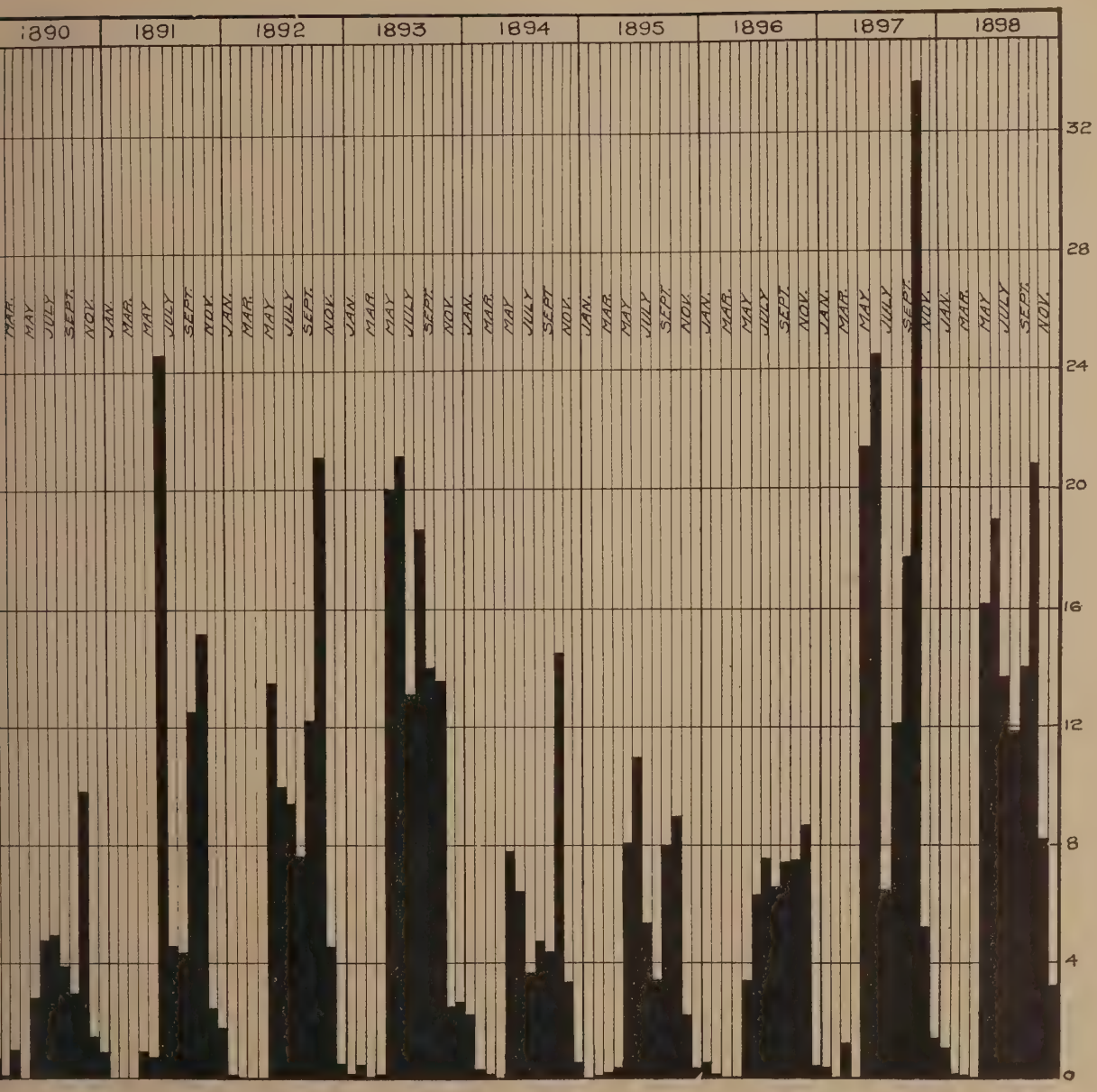
Fig. 7. Comparative Monthly Rainfall at Greytown, Ochoa, Ft. San Carlos and Tola.

[1] In Atlas.

NICARAGUA CANAL COMMISSION



MONTHLY RAIN


1890
1891
1892
1893
1894
1895
1896
1897
1898
32
28
24
20
16
12
8
4
0

AS, 1880-1898.

been prepared, representing as nearly as may be with present information the probable distribution and quantity of rainfall in the year 1890 in southern Nicaragua and northern Costa Rica in seven zones. The first, which includes the greater part of Lake Nicaragua and its drainage basin, has rainfall of less than 30 inches, probably in some parts running below 20 inches. The second zone represents a rainfall between 30 and 60 inches. The next has a precipitation ranging between 60 and 100 inches. The zone next further east represents a precipitation ranging between 100 and 150 inches. The next includes that portion in which the precipitation is between 150 and 200 inches, the next that portion between 200 and 250 inches, while the small triangular area about the mouth of the San Juan has a rainfall exceeding 250 inches.

The data upon which this map is made are the record of 19 years at Rivas, 4 years at Greytown, the record for 1898 at other stations maintained by the Nicaragua Canal Commission, and a few other records obtained through the courtesy of Prof. H. Pittier, San José, Costa Rica, and from the U. S. Weather Bureau. The record of Greytown includes the years 1890, 1891, 1892 and 1898, the latter being the record of the Nicaragua Canal Commission, aggregated 201.64. The year 1890 had a precipitation of 296.94, which exceeds that for 1898 by 47 per cent. It is assumed that this proportion between the rainfall of 1898 and 1890 exists for all of the country east of Lake Nicaragua, and 47 per cent. was therefore added to the observations at each of the stations maintained by the Commission to obtain the maximum for use in compiling this map. On the west side of Lake Nicaragua and at Morrito, which is affected by similar climatic conditions, the long record at Rivas was taken as the standard, and the rainfall for 1890 was obtained by taking 30 per cent. of the record for 1898, this being the percentage indicated by the Rivas record. There is some indication that the co-existence of extreme conditions on one side, with the opposite extreme on the other side is the rule. The year 1898 is the year of minimum precipitation at Greytown, so far as our record of complete years goes, while the record at Rivas gives for that year very nearly a maximum, being second only to the year 1897. Also the short record of five months for 1893 at Greytown gave a total for five months of 41.92, being much less than for the same period in any other recorded year at Greytown, indicating that 1893 was a year of low precipitation at this point, while it was one of the highest in the Rivas record. Of course these zones must be considered as only rough approximations.

MONTHLY RAINFALL AT RIVAS, NICARAGUA.
Dr. Earl Flint, Observer.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1880	0.00	0.00	0.00	0.00	10.23	12.58	3.62	10.48	7.95	13.83	5.02	0.67	64.38
1881	0.00	0.00	0.00	0.12	5.20	13.17	8.88	6.96	7.42	24.67	10.88	1.91	79.21
1882	0.00	0.13	0.00	0.00	4.26	9.80	4.04	6.25	7.65	23.38	4.20	1.61	61.32
1883	0.28	0.00	0.00	0.14	1.00	8.07	4.87	4.34	5.78	18.25	5.70	1.34	49.77
1884	0.59	0.09	0.00	2.03	2.80	10.43	4.98	3.84	4.48	15.83	7.43	2.24	54.74
1885	0.04	0.00	0.00	0.00	1.78	7.27	4.81	2.76	5.40	7.88	4.36	0.29	34.59
1886	0.23	0.20	0.00	0.17	13.00	7.87	15.00	20.80	15.30	10.40	3.75	0.49	87.21
1887	0.90	0.81	0.00	0.00	9.17	8.18	4.10	5.03	19.42	22.47	2.50	2.31	74.89
1888	1.83	0.04	0.00	0.00	7.12	8.50	4.18	5.00	9.80	16.80	1.11	1.13	55.51
1889	0.00	0.19	0.07	1.71	11.34	11.64	7.48	12.95	9.80	24.13	3.38	1.67	84.36

MONTHLY RAINFALL AT RIVAS, NICARAGUA.—Continued.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1890	0.49	0.11	0.94	0.00	2.63	4.56	4.73	3.78	2.77	9.68	1.30	0.82	31.81
1891	0.00	0.00	0.00	0.78	0.75	24.58	4.38	4.21	12.42	14.90	2.34	1.67	66.03
1892	0.19	0.00	0.00	0.00	13.30	9.80	9.19	7.48	12.22	21.26	4.40	0.43	78.27
1893	0.06	0.39	0.00	0.11	20.03	21.14	13.22	18.70	14.00	13.56	2.44	2.48	106.13
1894	2.12	0.24	0.08	0.00	7.76	6.32	3.64	4.57	4.33	14.62	3.21	0.43	47.32
1895	0.00	0.08	0.19	0.39	8.11	11.02	5.25	3.42	8.01	8.97	2.04	0.20	47.68
1896	0.40	0.08	0.00	T.	3.26	6.23	7.43	6.57	7.40	7.42	8.62	0.39	47.80
1897	0.33	T.	1.04	0.00	21.30	24.34	6.41	12.10	17.63	33.85	5.15	1.28	123.43
1898	1.07	0.12	0.10	0.00	16.17	18.95	13.65	11.85	13.99	20.83	8.19	3.14	108.06
Means	0.45	0.13	0.13	0.29	8.38	11.81	6.83	7.95	9.78	16.99	4.52	1.29	68.55

MONTHLY RAINFALL AT MASAYA, 1886-96, AND GRANADA, 1897.
Nicaragua Observers.

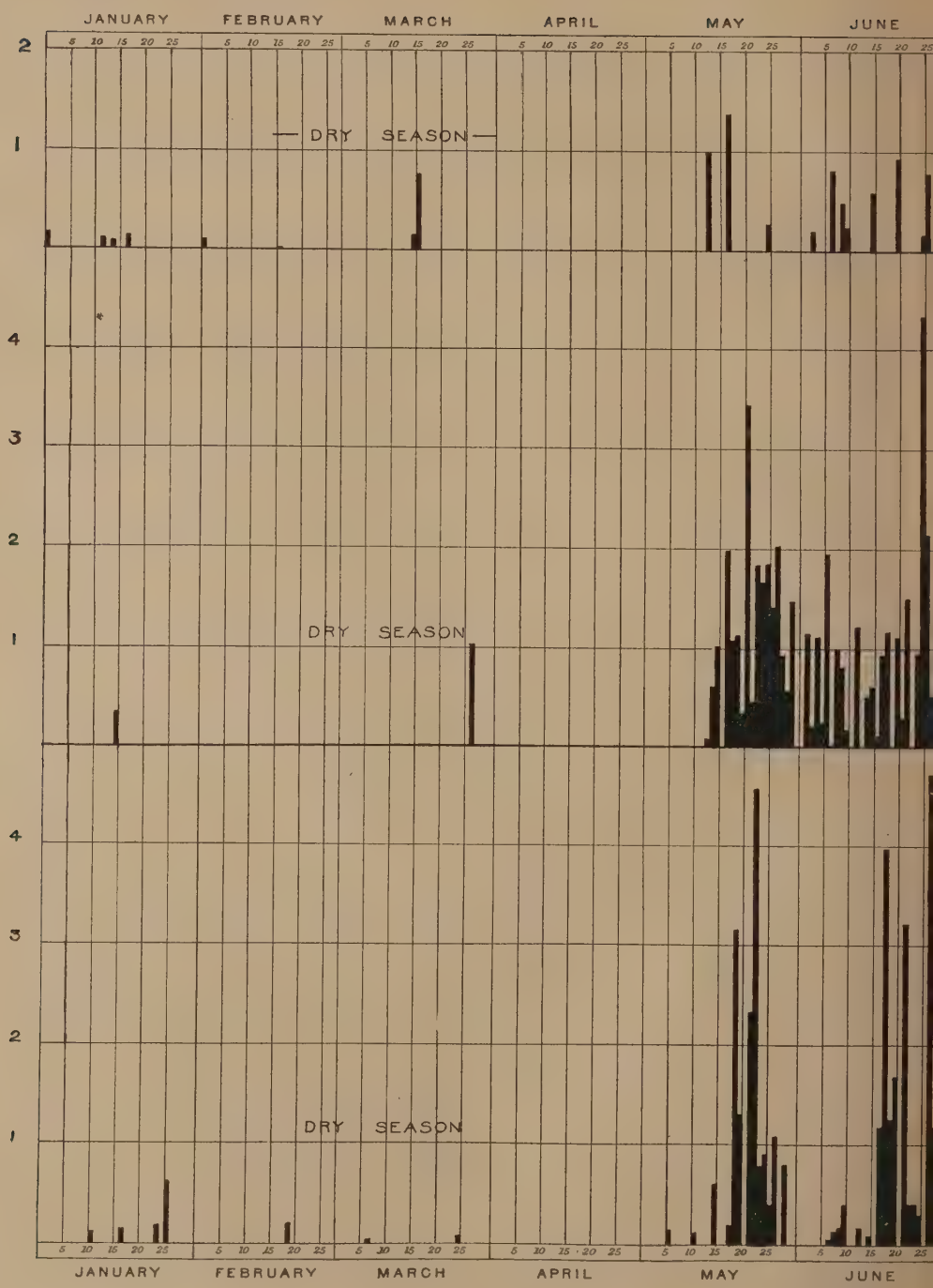
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1886....	....	....	....	*	....	....	8.23	15.26	15.34	11.19	0.69	0.02	72.70
1887....	0.30	0.00	0.00	0.00	2.42	10.73	7.39	5.74	9.15	23.56	0.94	0.99	61.22
1888....	0.05	0.14	0.00	0.00	7.09	12.09	4.95	9.50	17.21	7.67	0.00	0.00	58.70
1889....	0.00	0.00	2.39	1.18	6.43	17.00	7.87	13.43	14.53	13.36	2.34	0.25	78.78
1890....	0.14	0.00	0.00	0.60	1.82	3.00	2.86	2.66	2.95	5.89	0.42	0.18	20.52
1891....	0.19	0.00	0.00	1.02	0.48	20.94	4.52	4.20	10.40	5.45	2.78	0.00	49.98
1892....	0.00	0.00	0.00	0.00	7.36	14.42	8.70	6.75	9.64	15.71	1.66	0.30	64.54
1893....	0.00	1.15	0.00	0.00	9.26	11.78	11.47	15.82	12.67	6.51	2.70	1.50	72.86
1894....	0.32	0.50	0.00	0.00	7.87	4.77	3.32	4.00	7.49	13.43	1.08	0.11	42.88
1885....	0.00	0.00	0.00	0.41	4.57	4.71	5.22	2.90	8.36	14.46	0.57	0.06	41.26
1896....	0.23	0.00	0.00	0.09	5.62	7.90	7.13	2.98	6.62	4.22	4.85	0.00	39.64
1897....	0.00	0.00	0.97	1.77	16.63	30.79	8.88	10.87	10.21	11.97	1.25	0.28	93.62
Means ..	0.11	0.16	0.31	0.46	6.32	12.56	6.71	7.84	10.38	11.12	1.61	0.31	58.06

* Estimated rainfall January to June, 1886, inclusive, is 21.97 inches.

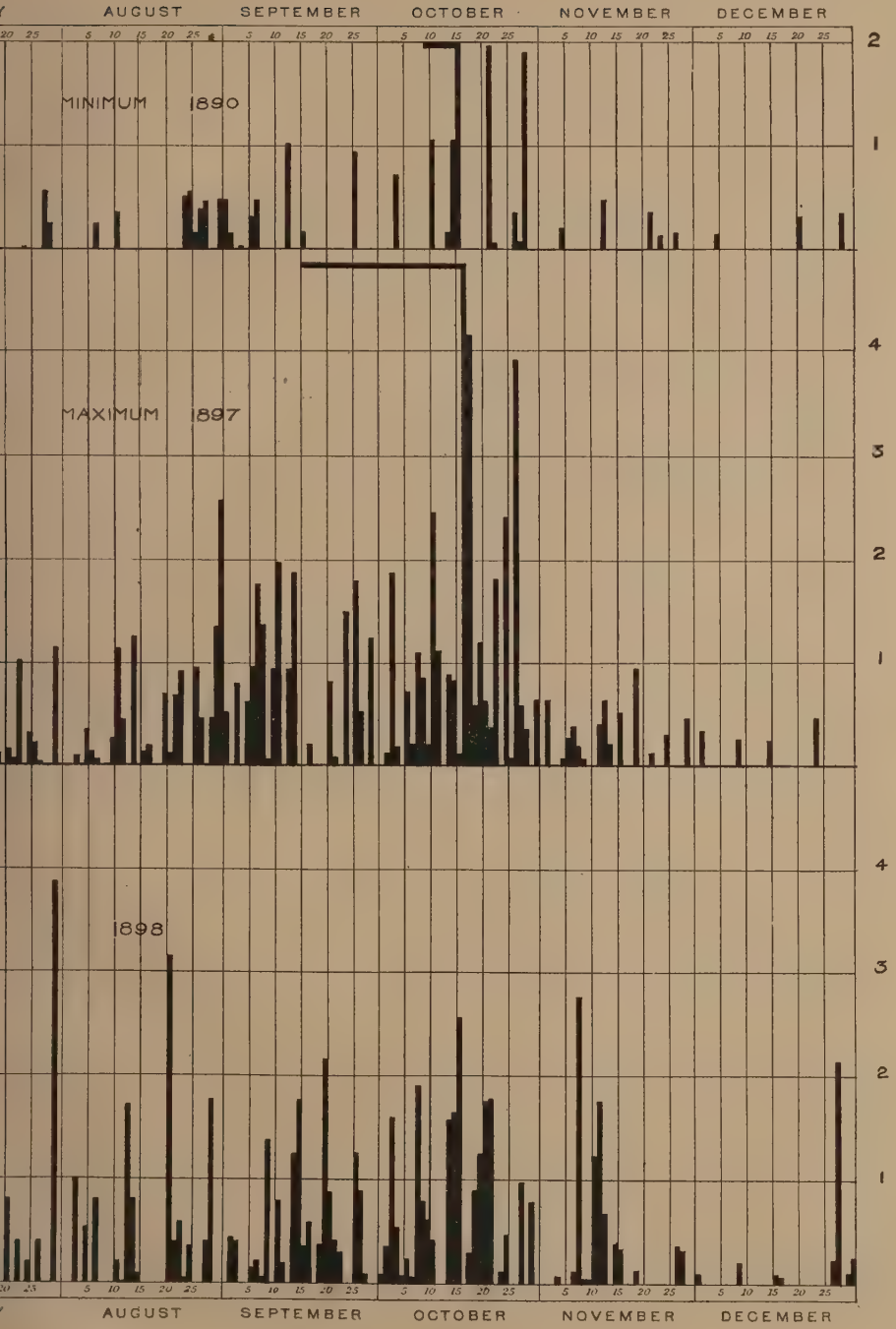
MONTHLY RAINFALL.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
						MANAGUA.							
				Lat. 12° 7′ N.		Long. 86° 16′ W.		Elevation 148 feet.					
1891....	.00	.00	.00	.00	1.08	14.00	5 04	3.04	8.43	9.64	7.24	0.43	48.90
1892....	.00	.00	.00	.00	8.58	11.34	6.35	7.98	9.24	20.55	3.09	....	67.13
						SAN ANTONIO.							
				Lat. 12° 32′ N.		Long. 86° 59′ W.		Elevation 66 feet.					
1895....	.00	.00	.00	....	7.98	6.29	3.36	5.07	21.68	21.71	3.42	0.32	69.83
1896....	.00	.00	.00	0.20	12.20	10.50	7.54	4.71	13.39	11.22	4.76	0.98	65.50
1897....	.00	.00	1.26	0.59	18.23	14.53	6.81	13.86	10.94	31.06	.98	.00	98.26
						VALLE MENIER.							
				Lat. 11° 46′ N.		Long. 85° 57′ W.		Elevation 492 feet.					
1880....	.00	.00	.00	.00	13.48	9.92	2.24	9.96	6.77	13.46	2.72	.00	58.55
1881....	0.55	.00	.00	.00	9.94	12.88	7.52	8.86	9.10	22.68	9.33	0.98	81.84
1882....	.00	.00	.00	.00	1.93	12.87		6.30	4.92	19.13	2.76	.00	47.91
1883....	.00	.00	.00	.00	1.35	7.44	3.94	....	....	....	....	....	....

NICARAGUA CANAL COMMISSION



DAILY RAINFALL AT


AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
MINIMUM 1890
MAXIMUM 1897
1898
5 10 15 20 25
1
2
3
4

, 1897, 1898.

MONTHLY RAINFALL AT GRANADA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total Annual.
1876....	..	..	..	..	5.77	13.65	26.61	4.96	..	..	..	..	..
1877....	0.00	0.00	0.00	0.00	11.57	10.24	10.12	5.32	17.36	5.27	0.87	0.59	61.34
1883....	0.35	0.00	0.00	0.18	0.28	5.20	2.66	5.47	9.74	19.91	3.64	0.00	47.43
1884....	0.00	0.00	0.00	0.00	0.00	8.25	3.99	3.75	8.82	8.63	2.28	0.26	35.98

1876.....Observer.....Ramon Espinola. 1877.....Observer.....Earl Flint.
Location, N. 11° 56′, W. 85° 54′; elevation, 218 ft.

1883–1884.....Observed by National Institute; elevation, 230 ft.

RAINFALL AT GREYTOWN, NICARAGUA.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1890.....	26.80	6.36	5.93	18.11	4.93	46.84	52.55	35.72	8.14	24.36	25.55	41.65	296.94
1891.....	20.30	2.57	1.95	10.40	13.78	26.95	23.57	19.49	14.16	20.21	28.15	32.74	214.27
1892.....	28.57	11.38	4.98	18.38	50.88	13.42	38.96	23.63	11.47	27.95	36.93	24.65	291.20
1893.....	17.70	7.53	3.93	9.99	2.77	....	....	....	....	....	....	....	....
1898.....	19.44	25.17	10.16	7.82	9.37	19.52	24.63	16.38	7.24	12.50	32.35	17.06	201.64

RAINFALL AT BLUEFIELDS, NICARAGUA.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1883.....	..	..	..	..	..	..	..	..	3.42	8.13	12.13	17.00	..
1884.....	10.25	6.39	3.21	2.06	2.67	8.01	17.06	16.40	5.82	4.99	9.71	11.15	97.72
1885.....	1.96	1.60	2.66	2.87	5.89	13.37	19.82	11.75	8.07	2.69	7.70	3.15	81.53
1886.....	7.28	3.94	1.63	..	..	..	..	8.55	..	..	..	..	..

DAILY RAINFALL FOR SAN JUAN RIVER AT SAN FRANCISCO ISLAND FOR 1888.
By Maritime Canal Co.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.....	....	....	....	....	....	....	2.61	3.27	.00	1.20	.14	.20
2.....	....	....	....	....	....	....	.87	.05	.00	.05	.00	2.15
3.....	....	....	....	....	....	....	.17	.53	.00	.10	.00	2.93
4.....	....	....	....	....	....	....	.77	1.87	.00	.00	.00	3.97
5.....	....	....	....	....	....	....	2.77	.43	.34	.17	.35	3.50
6.....	....	....	....	....	....	....	.09	.87	.00	.38	.13	.14
7.....	....	....	....	....	....	....	.07	1.11	2.47	.00	.11	.07
8.....	....	....	....	....	....	....	.11	.42	.57	.00	.08	.23
9.....	....	....	....	....	....	....	.73	.90	2.30	.00	.03	.05
10.....	....	....	....	....	....	....	.68	.00	.00	1.05	.73	.17
11.....	....	....	....	....	....	....	1.63	.52	2.70	1.27	2.24	.00
12.....	....	....	....	....	....	....	.92	.00	2.20	.92	.53	.05
13.....	....	....	....	....	....	....	1.93	.55	.40	.23	.62	.00
14.....	....	....	....	....	....	....	2.42	.13	.00	.07	.73	.00
15.....	....	....	....	....	....	....	2.70	.00	.34	1.25	.51	.05

DAILY RAINFALL OF SAN JUAN RIVER AT SAN FRANCISCO ISLAND FOR 1888.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
16.....	....	....	....	....	....	....	.87	.17	1.43	.37	.87	.63
17.....	....	....	....	....	....	....	.61	1.09	.57	1.85	1.94	.60
18.....	....	....	....	....	....	.23	.17	.13	.27	.63	.37	.05
19.....	....	....	....	....	....	.37	3.07	.73	.31	.69	.28	.77
20.....	....	....	....	....	....	.11	1.97	.64	.67	.99	.50	.69
21.....	....	....	....	....	....	.07	.23	.00	1.27	.26	.10	.00
22.....	....	....	....	....	....	.03	.17	.09	.59	1.60	.00	.00
23.....	....	....	....	....	....	.00	.32	.07	.00	.14	.14	.00
24.....	....	....	....	....	....	.49	1.07	.00	2.55	.06	.12	.00
25.....	....	....	....	....	....	.87	1.12	2.07	.00	.16	.28	.00
26.....	....	....	....	....	....	.21	1.74	.77	.00	.04	.04	.00
27.....	....	....	....	....	....	4.51	.47	.00	2.09	.05	.00	.02
28.....	....	....	....	....	....	.27	.79	.53	.00	.80	.00	1.10
29.....	....	....	....	....	....	.61	.17	1.23	.24	.76	.00	1.52
30.....	....	....	....	....	....	.21	2.47	.52	1.20	.41	.18	.55
31.....	....	....	....	....	....	....	.73	.73	....	.36	....	.64
	32.06	7.31	7.94	10.97	16.19	16.81	34.44	19.41	22.51	15.86	11.02	20.08

Total for year, 214.60 inches.

PRECIPITATION AT SAN JOSÉ, COSTA RICA.

Latitude, 9° 56′ N. Longitude, 84° 8′ W. Elevation, 3750 feet.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1866....	1.30	0.28	0.00	1.14	5.47	4.84	12.60	6.14	10.79	9.84	6.73	4.80	63.93
1867....	3.86	2.21	0.38	3.86	8.23	8.11	8.43	7.48	12.36	8.39	9.61	0.55	73.47
1868....	0.00	0.00	7.13	0.01	2.27	5.91	4.02	5.12	8.82	15.47	5.67	0.67	56.09
1869....	0.28	0.00	0.28	1.10	7.95	8.58	5.91	5.20	15.47	11.06	3.07	4.02	62.92
1870....	0.04	0.24	1.22	0.67	13.11	10.87	9.45	11.18	9.45	10.32	7.24	1.30	75.09
1871....	1.10	0.12	0.32	0.51	11.42	7.99	14.33	12.09	9.65	13.11	4.49	0.43	75.56
1872....	0.12	0.12	0.59	1.97	9.61	10.04	7.56	14.88	15.63	19.84	5.59	0.83	86.78
1873....	2.52	0.00	0.12	2.80	2.52	8.07	5.71	3.35	15.24	10.32	4.76	0.43	55.84
1874....	1.81	0.04	0.79	2.36	13.23	6.57	6.38	7.13	12.56	7.52	1.65	0.79	60.83
1875....	0.00	0.00	0.00	1.10	9.92	7.09	3.66	11.57	10.98	13.35	0.83	1.26	59.76
1876....	0.55	0.00	0.43	0.24	9.72	9.33	6.02	7.56	8.11	4.61	2.76	1.10	50.43
1877....	0.55	0.00	0.00	0.00	9.45	6.57	8.78	6.26	10.20	3.74	4.76	3.11	53.42
1878....	0.00	0.00	1.50	1.97	3.59	7.36	8.07	5.87	12.99	9.37	8.78	0.79	60.29
1879....	0.51	0.00	1.77	7.56	8.66	12.99	18 11	11.14	13.82	9.09	2.40	0.32	86.37
1880....	0.32	0.00	0.00	0.59	10.00	8.27	4.09	17.17	6.50	10.94	3.62	0.00	61.50
1884....	0.00	0.00	0.08	0.32	0.43	2.44	0.59	0.67	4.41	1.89	7.44	1.22	19.49
1885....	0.00	0.00	0.00	1.85	5.98	3.07	7.84	3.86	15.59	12.87	16.22	2.32	69.60
1886....	0.00	0.00	2.05	8.98	15.55	16.85	20.59	19.61	22.91	28.67	16.81	2.28	154.30
1887....	0.00	0.00	0.67	0.28	9.96	14.16	5.61	9.40	11.24	13.16	4.93	2.07	71.48
1888....	0.63	0.71	0.00	0.55	7.07	10.24	5.49	5.54	15.71	10.39	2.01	0.87	59.21
1889....	0.01	0.08	2.91	2.41	14.57	8.08	6.06	10.76	16.89	20.48	2.45	0.48	85.18
1890....	0.87	0.08	0.75	2.52	10.08	11.65	15.67	10.55	8.35	7.99	2.56	0.71	71.78
1891....	0.03	0.01	0.05	0.74	4.26	7.74	8.00	9.84	12.30	15.48	5.57	1.16	65.18
1892....	0.00	0.00	0.13	0.07	12.17	15.06	8.70	13.75	14.84	21.36	5.03	0.44	91.55
1893....	0.04	0.00	0.02	0.47	8.73	15.28	13.90	13.76	20.75	14.93	7.08	2.94	97.90
1894....	0.04	0.00	0.00	0.99	8.00	7.83	3.90	9.76	12.80	8.54	5.82	0.55	58.23
1895....	0.15	0.35	0.04	0.86	15.12	12.36	4.76	9.92	11.50	7.32	8.35	6.02	76.75
1896....	2.13	0.00	0.04	5.20	6.57	6.50	8.23	4.88	8.15	7.87	12.16	3.03	64.76
1897....	0.20	0.00	0.28	1.54	12.20	8.98	4.33	15.75	12.05	14.92	3.11	1.61	74.97
1898....	0.35	0.00	0.28	1.30	8.58	15.59	8.90	13.39	13.62	11.69	4.65	0.08	78.43

RAINFALL IN COSTA RICA.

N. B.—The stations in Italic are on the Caribbean side of the main cordillera.

Stations.	Long. W. of Greenwich.	Lat. N.	Altitude.	Years of observation.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	
																	Millim.	Inches.
			m.	Yrs.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.		
Boca Banana.	83° 01′ 51″	9° 56′ 23″	3	3	360	146	175	553	189	199	288	316	78	173	244	371	3,092	121.73
Port Limon..	83° 03′ 13″	10° 00′ 21″	3	2	224	210	225	242	289	205	530	248	101	99	356	266	2,995	117.92
Matima	83° 22′ 03″	10° 05′ 33″	40	3	510	276	131	508	230	206	292	256	95	111	297	493	3,405	134.06
Jimenez	± 83° 48′	± 10° 13′ 38″	250	1	458	135	223	284	422	261	204	390	183	456	238	635	3,889	153.11
Turrialba ...	± 83° 47′	± 9° 55′ 00″	643	5	229	53	79	270	241	315	229	255	255	241	190	452	2,809	110.59
Tuis	± 83° 38′	± 9° 51′ 00″	650	2	170	95	54	267	305	271	234	149	278	201	197	469	2,690	105.90
Juan Viñas..	± 83° 45′	± 9° 55′ 00″	1,140	2½	333	83	118	127	182	189	167	219	184	199	173	354	2,328	91.65
Cartago	± 83° 55′	± 9° 55′ 00″	1,476	3	95	44	23	68	180	130	81	160	183	283	89	87	1,423	56.03
Aguacaliente .	± 83° 57′	± 9° 54′ 00″	1,364	2	43	9	36	41	189	135	111	187	182	267	36	152	1,388	54.65
Tres Rios ...	± 83° 57′	± 9° 55′ 48″	1,300	7	10	1	4	72	361	262	170	248	334	437	171	52	2,122	83.55
La Verbena .	± 84° 03′ 30″	± 9° 55′ 10″	1,140	2	0	0	19	58	356	363	188	230	318	372	187	49	2,140	84.26
San José....	84° 03′ 19″	9° 56′ 01″	1,160	10	10	1	11	41	255	277	209	285	333	332	149	45	1,948	76.69
SanFrancisco	± 84° 03′ 07″	± 9° 56′ 34″	1,200	3	23	0	9	74	240	274	185	282	284	306	174	33	1,884	74.18
Heredia.....	± 84° 09′	± 9° 59′ 00″	1,180	3	41	8	1	21	55	226	220	144	137	236	361	104	1,554	61.19
La Palma on the divide.	± 83° 59′ 11″	± 10° 02′ 39″	1,460	2	469	75	69	187	254	430	288	270	233	235	280	633	3,423	134.77
San Carlos...	± 84° 31′	± 10° 24′ 00″	50	½	196	..	..	..	..	..	..	331	336	341	388	156	..	..

Evaporation.

The rate of evaporation in the region of Lake Nicaragua has an important bearing upon the practicability of maintaining the summit level of the canal under any plan yet proposed, and upon the means that must be provided for the maintenance of such level.

Observations have shown that the inflow to Lake Nicaragua during the dry season is very small and indicate that in some years it is practically zero for a considerable period, during the dry season, while at the same time, evaporation is at its maximum. For the purpose of ascertaining the amount of this evaporation, observations were taken at Fort San Carlos, San Ubaldo and Las Lajas. For this purpose evaporation pans were provided, which were made of galvanized sheet-iron about three feet square and two feet deep. The pan was anchored in some protected body of water, filled nearly full and floated by means of wooden buoys, fastened to the sides. A scale was provided reading to five-hundredths of an inch, and by estimation to single hundredths. On this the height of the water was read each day, which was compared with the reading at the same hour on the previous day. The rainfall was measured by means of a rain gage, located in the immediate vicinity and its result applied as a correction to the change of water elevation in the pan.

The obstacles to continuous, reliable observations of evaporation are many. The pan was sometimes driven aground by winds and storms and the water spilled. Sometimes a leak would be caused in this way. Other causes tended occasionally to vitiate results, an idea of which may be formed from the following notes taken from the observer's note-book:

"Heavy sea filled the pan.

"Evaporating pan blown on the beach with bottom broken.

"Soap found in pan; some one had been taking a bath.

"Sand cleaned out of pan.

"Pan swamped.

"Pan shelved.

"Reading useless on account of waves breaking into pan."

At Las Lajas the pan was disturbed at first by cattle. This was remedied by anchoring it in water too deep for them. At San Carlos the pan became at times a favorite roost for birds and a scarecrow had to be provided to keep them away. However, it was usually possible to judge correctly as to whether the observations had been vitiated and care was taken to eliminate those with regard to which a reasonable doubt existed. As might be expected from the above, there are many breaks in the continuity of observations, days being omitted on account of doubtful conditions.

In the following tables the daily mean in each case represents the mean of good observations, this being multiplied by the number of days in the month to obtain the total for the month.

As there was usually some motion to the water in the pan it was not always practicable to read the scale correctly within a tenth of an inch, but whatever error occurs from this cause applies with opposite sign to results preceding and following the observation and the error is thus eliminated. The seeming fluctuation, therefore, which might be inferred from the table of observations is chiefly due to this cause and in the main is unavoidable, and in any event does not affect results, except in a slight degree at the beginning and end of a series of continuous observations.

Allowance must be made in the use of these results for the fact that the conditions obtaining on the lake cannot be duplicated in the evaporating pan. During the dry season the trade winds blow strongly from the eastern side of the lake to the western. Except along the eastern shore the surface of the lake is blown into billows, the waves often attaining a considerable height and being crowned with whitecaps. In this way a large quantity of spray is thrown into the air, and the total water surface in contact with the trade wind is much greater than the level surface of the lake. More than half the area of the lake, therefore, must lose by evaporation a greater depth of water than the pan.

The observations taken furnish another method of computing the evaporation from the lake.

Records showing the height of the surface of the lake were kept at San Carlos, San Ubaldo and Las Lajas. Observations of rainfall were taken at all these places, and at Tipitapa, about ten miles northwest of the lake. A circuit of the lake was made in April and May, for the purpose of measuring the inflowing streams. A record of the discharge of San Juan river was kept at Sabalos, above Toro rapids. From April 10 to May 10 the lake fell 8.64 inches. During the same time rain fell as follows:

	Inches.
San Carlos	3.20
Las Lajas	.22
San Ubaldo	.50
Tipitapa	.00
Sum	3.92
Mean	.98

The measured outflow was 714,000 acre-feet, and the inflow is estimated to have been 120,000 acre-feet, making a net decrease of 3.50 inches in lake elevation, due to flowage.

Assembling these facts, we have

$$\text{Evaporation} = 8.64 + .98 - 3.50 = 6.12.$$

During the same time the evaporation observed was as follows:

	Inches.
San Carlos	4.77
Tipitapa	6.05
San Ubaldo	6.30
Las Lajas	7.89
Sum	25.01
Mean	6.25

This is a close check, and indicates that either method would afford a fair approximation of the amount of the evaporation. Being the last month of the dry season, it probably represents about the maximum for the year. The rainfall records for Rivas and also for Masaya show that 1897 was the year of maximum rainfall so far as observed, and 1898, appears to be above the average, so that during the season under consideration the evaporation was probably not as great as it sometimes becomes, and in the dryest years may approach seven inches in one month.

The usual dry season at Rivas is from about the middle of December to the middle of May. It doubtless begins earlier and ends later in the years of least rainfall, and may continue over six months.

EVAPORATION, LAS LAJAS, NICARAGUA.

Day.	1898. Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	1899. Jan.	Feb.	Mar.
1	....	.30	.24	....	.04	....	.10	....	.10	.10		....	....
2	....	.31	.26	....	.17	....	.11	.05	.10	.02	.30	.09	.10
3	....	.34	.24	....	....	....	.09	....	.15	.07		.14	.12
4	....	.28	.27	.14	....	.12	....	.06	....	.07	.12	.07	.18
5	....	.28	.25	.20	....	.13	.10	....	....	.10	.15	.11	.13
6	....	.21	.27	.13	....	....	.10	....	.10	.11	.09	.10	.20
7	....	.24	.23	.22	.19	.06	.13	....	.10	.10	.12		
8	....	.35	.27	.20	.14	.11	.08	.16	.22	.09	.12	.22	.25
9	....	.31	.32	.21	.17	.08	.15	....	.12	.05	.08	.13	.23
10	....	.27	.29	.19	.18	.09	.16	.05	.05	.14	.09		.12
11	....	.23	.24	.14	....	.05	.11	.07	....	.08	.13	.32	.10
12	....	.33	....	.24	.19	.18	.15	.05	....	.11	.08		.15
13	....	.30	.21	.17	.12	.12	....	.10	....	.12	.11	.12	.10
14	....	.24	.28	....	.09	.14	.02	.05	.08	.10	.10	.18	.17
15	....	....	.10	....	.13	.11	.10	....	.03	.10	.10	.11	.08
16	....	.17	.19	.15	.06	.09	.10	....	....	.09	.12	.12	.11
17	....	.24	.25	.07	.03	.11	.11	.14	....	.07	.13	.30	.14
18	....	.21	.16	.17	....	.16	.04	.16	....	.08	.10	.10	
19	....	.28	.16	.10	....	.08	.09	.13	.09	.09	.10	.20	.30
20	....	.26	.04	.07	.11	.13	.11	.05	.03	.11	.10	.08	.15
21	....	.37	.13	.18	....	....	.04	.13	.04	.04	.12	.09	.07
22	.10	.28	....	....	.07	.15	.11	.04	.10	.15	.07	.09	.11
23	.20	.39	....	.12	....	.08	....	....		.10	.11	.11	.17
24	.07	.23	....	.01	....	.10	.04	....	.45	.14			
25	.18	.20	.04	.05	.07	....	.08	....		.13	.27	.22	.28

EVAPORATION, LAS LAJAS, NICARAGUA.—Continued.

Day.	Mar. 1898.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.
26.....	.18	.34	.03	....	.03	.10	.05	....	.15	.12	.08	.11	.33
27.....	.22	.28	.13	....	.05	.12	....	....	....	.13	.09	.15	.04
28.....	.32	.26	.10	....	.11	.16	.02	....	.07	.09	.12	.11	.05
29.....	.15	.25	.12	....	.12	....	.10	.10	.06	.06	.12	....	.17
30.....	....	.22	....	.14	....	....	.08	.10	.06	.11	.16	....	.13
31.....	.25	....	....	....	....	.05	....	.07	....	.12	.12	....	.13
Mean...	.186	.271	.193	.145	.109	.110	.091	.088	0.100	.097	.110	.121	.137
Total...	5.77	8.13	5.98	4.35	3.38	3.41	2.73	2.73	3.00	3.01	3.40	3.39	4.25

EVAPORATION, SAN UBALDO AND MORRITO, NICARAGUA, 1898.

Day.	April.	May.	June.	July.	August.	September.
1.....	....	.22	....	.10	.15	.07
2.....	....	.15	.20	.12	.01	.12
3.....	....	.30	.05	.21	.13	.19
4.....	....	.20	.09	.15	.25	.23
5.....	....	.19	.02	.15	.12	.07
6.....	....	.17	.25	.13	.18	.18
7.....	....	.23	....	.10	.19	.15
8.....	....	.22	.17	.11	.15	.11
9.....	....	.14	.32	.11	.12	.10
10.....	.32	.25	.36	.12	.22	.23
11.....	.20	.13	.08	....	.14	....
12.....	.15	.20	.21	.25	.22	....
13.....	.20	.30	.13	.35	.15	....
14.....	.25	.25	.14	.21	....	....
15.....	.10	.06	.20	.21	....	....
16.....	.30	.19	.20	.12	.08	....
17.....	.12	.20	.15	....	.15	....
18.....	.15	.16	.13	.. .	.10	....
19.....	.25	....	.23	....	.14	....
20.....	.30	....	.15	.21	.31	....
21.....	.15	....	....	.17	.22	....
22.....	.20	....	....	.05	.17	....
23.....	.18	....	.22	.15	.09	....
24.....	.27	....	.17	.28	.20	....
25.....	.25	....	.26	....	.08	....
26.....	.26	....	.13	.05	.14	....
27.....	.25	.30	.28	.27	.17	....
28.....	.25	.25	.02	....	.17	....
29..... ..	.17	.31	.20	....	.12	....
30.....	.18	.03	.14	....	.20	....
31.....	....	....	....	....	.18	....
Mean.....	.214	.202	.173	.164	.157	.145
Total.....	6.42	6.26	5.19	5.08	4.87	4.35

EVAPORATION, FORT SAN CARLOS, NICARAGUA.

Day.	Mar. 1898.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.	Mar.	Apr.
1....	....	.15	....	.11	.19	.06	.22	.20	.14	....	....	.15	.11	.15
2....	....	.20	.21	.18	.23	.09	.13	....	.20	.12	.15	.15	.15	.15
3....	....	.16	.16	.18	.13	.11	.14	.06	.15	.12	....	.10	.11	....
4....	....	.19	.16	.18	.05	.10	....	.13	.20	.15	....	.15	.15	....
5....	....	.09	.08	.12	.10	.09	.07	....	.10	.19	.12	.15	.10	.17
6....	....	.01	.20	.10	....	.14	.07	....	.10	.11	.15	.14	.12	.12
7....	....	...	.18	.07	.14	.14	.09	....	.15	.18	.13	.10	....	....
8....	....	.17	.15	.21	.12	.18	.06	....	....•	.14	.10	....	....	....
9....	.12	.19	.22	.11	.10	.11	.06	.11	.07	.14	.08	....	....	.14
10....	.01	.13	....	.20	.11	...	.18	.12	.08	....	.08	.10	...	....
11....	....	.16	....	.10	....	.11	.20	....	.12	.15	.10	....	....	.10
12....	.12	.18	....	.11	....	.11	....	.13	{.25	.12	.08	.11	.14	....
13....	.08	.12	....	.16	.18	.11	....	.14	{	....	....	.08	.15	.15
14....	.17	.13	....	.29	.09	.12	....	.10	.09	.15	....	.15	.10	.10
15....	.06	.17	....	.07	.15	.06	....	.09	.05	.15	....	.13	.10	.15
16....	.19	.26	....	.09	.13	.10	.12	.15	....	.11	.10	.06	.10	.15
17....	.15	.09	....	....	.12	.12	.22	....	....	.14	.10	.07	.15	.20
18....	.21	.15	.05	.12	.12	.19	.17	....	.06	.12	.11	.08	.15	.15
19....	.19	.08	....	....	.31	.21	.04	....	.10	.15	.15	.12	.15	.20
20....	.20	.18	.22	...	.07	.14	.09	.11	.10	.10	.10	.10	.15	.20
21....	.20	.22	....	....	...	.12	.08	....	.13	.05	.22	.10	.15	.20
22....	....	.11	....	....	.12	.14	.05	.19	....	.15	.18	.15	.15	.20
23....	.14	.16	....	.17	...	.13	.06	....	.15	.10	.15	.15	.15	.20
24....	.22	.15	....	...	...	.07	.15	....	{.15	{.20	.15	....	.15	.15
25....	.14	.17	....	.12	.10	.09	.15	.14	{		.10	....	.20	.15
26....	.23	.11	....	.11	.12	.11	....	....	.10	.17	.10	.10	.15	.20
27....	.12	.16	....	.25	.08	.11	.10	....	.08	.09	.10	.10	.15	.15
28....	.15	.18	.07	.12	.05	.14	.15	...	.08	.13	.10	.15	.15	.20
29....	.21	.16	.12	.12	.07	.17	....	.15	.18	.09	.10	....	.15	.20
30....	....	.15	.12	.07	.11	.11	....	.15	....	.06	.15	....	.20	.25
31....	....	....	.12	....	.10	.09	....	.15	....	.09	....	....	.10	....
Mean.	.153	.164	.147	.140	.124	.119	.118	.132	.113	.130	.121	.117	.140	.168
Totals	4.74	4.92	4.56	4.20	3.84	3.69	3.54	4.09	3.39	4.03	3.75	3.28	4.34	5.04

ESTIMATED MONTHLY EVAPORATION OF LAKE NICARAGUA.

Month.	Discharge in Second-Feet.			Total for month.	Month.	Discharge in Second-Feet.			Total for month.
	San Ubaldo.	Las Lajas.	Ft. San Carlos.			San Ubaldo.	Las Lajas	Ft. San Carlos.	
1898.	Inches.	Inches.	Inches.	Mean.	1898.	Inches.	Inches.	Inches.	Mean.
March	....	5.77	4.74	5.25	October...	....	2.73	4.09	3.41
April	6.42	8.13	4.92	6.49	November.	....	3.00	3.39	3.20
May	6.26	5.98	4.56	5.60	December.	....	3.01	4.03	3.52
June.....	5.19	4.35	4.20	4.58	1899.				
July	5.08	3.38	3.84	4.10	January...	....	3.40	3.75	3.57
August ...	4.87	3.41	3.69	3.99	February..	....	3.39	3.28	3.34
September.	....	2.73	3.54	3.13	March	....	4.25	4.34	4.30

EVAPORATION, TIPITAPA, NICARAGUA.

Day.	Feb. 1898.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.
1	....	.20	.10	.10	.20	.10	.12	....	.20	....	.02	.07
2	.30	.30	.20	.20	....	....	....	....	.14	....	.10	.20
3	.10	.20	....	.10	.20	.20	....	.14	.16	....	.04	.10
4	.30	....	....	.30	.21	.20	....	.13	.09	....	.12	....
5	.30	.20	.10	.15	.20	.20	10	.07		....	.10	.10
6	.35	.30	.30	.15	.20	.13	.10	.09	.20	....	.22	.15
7	.30	.20	.10	.20	.23	.15	....	.09	.15	....	.17	.13
8	.10	.20	.10	.25	....	.10	.11	.12	.40	....	.18	.12
9	.20	.20	.20	.20	.05	.10	.19	.10		....	.10	.20
10	.20	.20	.10	.20	.21	.24	.16	.14	.12	....	.10	.10
11	.10	.30	.30	.30	.28	.10	.15	.18	.13	....	.12	.15
12	.10	.10	.20	.25	....	.10	.12	.23	.17	....	.18	.20
13	.10	.10	.20	.10	.29	.15	.16	....	.09	....	.15	.10
14	.20	.20	.10	....	.10	.10	.17	.20	.10	....	.15	.15
15	.20	.20	.10	....	.15	.15	.25	.16	.11	....	.15	.10
16	.10	.30	.30	.07	.30	.10	.08	....	.11	....	.20	.10
17	.30	.20	.20	....	.10	.15	.19	.10	....	....	.10	.11
18	.10	.20	.20	....	....	.14	.16	.07	....	....	.22	.15
19	.20	....	.20	.21	.17	....	.19	.13	....	.11	.10	.18
20	.20	.30	.30	.11	.12	.10	.17	.13	....	.14	.20	.20
21	.30	.30	.30	.34	....	.24	.11	.14	....	.13	.16	.22
22	.20	.10	.25	.18	.. .	.03	.17	.10	....	.10		.20
23	....	....	.15	.12	.10	.15	....	.10	....	.14	.44	.20
24	.20	.30	.30	.20	.12	.20	.10	.14	....	.13		....
25	.30	.30	.10	.02	....	.15	.16	.13	....	.14		....
26	.30	....	.10	....	.25	.15	.12	....	....	.13	.17	....
27	.20	.30	.30	.12	.11	.27	.14	....	....	.17	.20	....
28	.10	.30	.20	.20	.19	.07	.10	.14	....	.14	.05	....
29	....	.30	.20	.20	.15	.17	....	.17	....	.16	.20	....
30	....	.20	.20	.10	.22	.09	.12	.10	....	.12	.13	....
31	....	....	....	.33	....	.15	....	....	....	....	.08	....
Mean	.206	.231	.193	.180	.180	.144	.143	.129	.136	.134	.134	.147
Total	5.77	7.16	5.79	5.60	5.40	4.46	4.43	3.87	4.22	4.02	4.15	4.56

EVAPORATION, SAN CARLOS RIVER, NICARAGUA, 1898.

Day.	March.	April.	May.	June.
1	....	.09	....	.13
2	....	.05	....	.13
3	.08	.06	.13	.08
4	....	.12	....	.10
5	....	....	....	.05
6	....	....	.02	.10
7	.13	....	.05	.04
8	.05	....	.06	.04
9	....	.15	.12	.10
10	.13	.13	.13	....

EVAPORATION, SAN CARLOS RIVER, NICARAGUA, 1898.—Continued.

Day.	March.	April.	May.	June.
11	.02	....	....	....
12	.06	.06	...	.10
13	.05	.10	.21	....
14	.04	.11	.08	....
15	....	.08	...	.15
16	...	.08	....	....
17	....	.10	.10	....
18	....	....	.09	....
19	....	.10	....	....
20	....	.07	.11	....
21	....	.12	.12	....
22	....	.04	.13	....
23	...	....	.03	....
24	....	....	.10	....
25	....	.09	.10	...
26	...	.06	.07	....
27	....	....	.07	....
28	....	....	....	....
29	.08	....	....	....
30	.13	.10	....	....
31	....	....	....	....
Mean	.077	.090	.095	.093
Total	2.39	2.70	2.95	2.79

EVAPORATION, OCHOA, NICARAGUA.

Day.	Mar. 1898.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.
1	....	.04	.10	.03	.08	.08	.11	.10	.05	.05	....	.12
2	....	.03	.07	.10	.06	.02	.06	.09	.05	.04	....	.05
3	....	.11	.14	.10	....	.06	.04	.07	.05	.03	.10	.10
4	.03	....	.20	.08	.02	.01	.07	.05	.07	.03	.10	.07
5	.17	.25	.11	.07	.11	.11	.04	.09	.03	.03	.06	....
6	.14	.02	.04	.10	.03	.01	.03	.11	.12	.09	.08	.08
7	.18	.09	.20	.09	....	.06	.03	.01	.04	.09	.06	.05
8	.13	.09	.16	.07	....	.03	.09	.11	....	.06	.09	.08
9	.15	.11	.13	.11	....	.11	.03	.05	.03	.04	.04	.10
10	.09	.19	....	.05	....	.04	....	.07	....	.06	.14	.05
11	.03	.04	.09	.06	....	.02	.06	.05	....	.03	.06	.07
12	.05	.11	.12	.16	....	.06	...	.08	.08	.06	.04	.04
13	.20	.11	.07	.06	....	.11	.10	.04	.11	.06	.08	....
14	....	.12	.08	.09	....	.11	.03	.05	.04	.02	.02	.03
15	.27	.12	.08	.05	...	.05	.03	.03	....	.08	.07	.06
16	....	.11	.08	.02	....	.07	.07	.06	....	.07	.12	.08
17	....	.10	.09	.05	....	.05	.08	.02	....	.09	.09	.02
18	.14	.13	.11	....	....	.04	.05	.09	....	.03	....	.06
19	.26	.08	.21	.15	....	.06	.03	.12	....	.08	.02	.11
20	.15	.13	.09	.17	....	....	.04	.03	.03	.03	.05	.07

EVAPORATION, OCHOA, NICARAGUA.—Continued.

Day.	Mar. 1898.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1899.	Feb.
21....	.04	.13	....	.09	....	....	.12	.02	.07	.06	.04	.02
22....	.10	.10	.04	.08	....	....	.15	.09	.03	.07	.09	....
23....	.12	.06	.02	.07	....	....	.03	.09	.04	.09	.05	.08
24....	.10	.11	....	.28	....	....	.06	.15	.05	.07	.08	.07
25....	.06	.11	....	.13	....	....	....	.02	....	.04	.03	.02
26....	.17	.15	.09	.12	....	....	....	.01	.08	.13	.04	....
27....	.12	.16	.11	.03	....	....	.08	.05	.10	.06	.11	.10
28....	.03	.11	.02	.09	....	....	.04	.04	.07	.07	.02	.08
29....	.09	.16	.19	.01	.06	....	.05	.02	.05	.06	.09	....
30....	.07	.12	.25	.08	.04	.04	.11	....	....	.09	.04	....
31....	.24	....	.05	....	....	.03	....	....	....	.06	.05	....
Mean.	.125	.110	.109	.089	.070	.056	.063	.062	.060	.060	.066	.067
Total.	3.88	3.30	3.38	2.67	2.17	1.74	1.89	1.92	1.80	1.87	2.05	1.88

EVAPORATION, GREYTOWN, NICARAGUA, 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug	Sept.	Oct.	Nov.	Dec.
1.....	.01	04	.13	....	.18	....	....	.24	....	....	....	.10
2.....	.21	.08	.25	....	....	....	....	.25	....	....	....	....
3.....	.38	.04	.10	....	....	....	....	....	....	....	....	.02
4.....	.08	....	.22	....	....	....	....	....	....	.21	....	.15
5.....	....	.05	.39	....	....	....	....	.20	....	.08	....	
6.....	.06	....	.22	....	....	....	....	....	.05	....	....	.11
7.....	.06	....	.37	....	....	....	....	....	.25	....	....	.14
8.....	.44	.25	.08	....	....	....	....	....	.10	.02	....	.05
9.....	....	.20	....	....	.27	....	....	....	....	.05	....	04
10.....	.05	.19	....	....	....	....	....	....	.10	....	....	.....
11.....	04	.20	.20	....	.06	....	....	....	.15	....	....	.08
12.....	.02	.27	.35	....	.35	....	....	....	....	.17	....	.07
13.....	....	....	.30	....	.18	....	....	.27	....	.06	....	.04
14.....	.13	.19	.35	....	.27	....	....	....	....	....	....	.15
15.....	.09	....	.40	....	.10	....	....	.10	.10	.04	....	.10
16.....	.16	.30	.25	.30	.39	....	....	.30	.20	....	....	.09
17.....	.21	.13	.18	.05	....	....	....	.01	.15	....	....	.10
18.....	.05	.15	.25	.20	...	....	....	.15	.10	.07	....	.04
19.....	.06	.19	.30	.10	.03	....	....	.10	....	.12	....	.15
20.....	04	.12	.20	.20	.28	....	....	.34	.10	.10	....	.08
21.....	....	.12	.15	.20	.13	....	....	.08	.07	.02	....	.11
22.....	.08	.14	.23	....	.07	....	....	.10	....	.13	....	.03
23.....	.09	.28	.19	....	.35	....	....	.15	....	.12	....	.07
24.....	.10	.12	.21	.25	....	....	....	.15	....	.14	....	.12
25.....	.12	15	.08	.12	.40	....	....	.25	....	....	....	.15
26.....	....	.18	.27	.10	.05	....	....	.30	....	.13	....	.09
27.....	.09	....	.17	.05	.05	....	....	.05	....	.07	....	.19
28.....	.37	.15	.30	.39	.05	....	....	.10	....	....	....	
29.....	.23	....	.30	.40	.05	....	....	.25	....	....	....	....
30.....	.25	....	....	.15	.05	....	....	....	....	....	....	.09
31.....	.18	....	....	....	.23	....	....	.18	....	....	....	.07
Mean...	.138	.161	.238	.193	.177	....	....	.178	.125	.096	....	.083
Total...	4.28	4.51	7.38	5.79	5.49	....	....	5.52	3.75	2.98	....	2.57

Water Supply.

In contemplating any canal in which locks are to be used the first question occurring to the investigator is with regard to the adequacy of water supply; and in a country with a dry season as definite and prolonged as that of the region tributary to Lake Nicaragua, storage of water must be provided against evaporation, leakage and use during the dry season. The Nicaragua Canal project is exceedingly fortunate in having at its summit level Lake Nicaragua, a magnificent natural reservoir, fed by an ample drainage basin. This reservoir is useful not only for storing water for use of the canal, but also as a regulator for the control of great floods that could hardly be provided for at practicable cost without its aid. On the other hand, the lake exposes its vast surface of two million acres of water to the constant action of the trade winds, and observations indicate that the lake loses about 17,000 cubic feet per second by evaporation during the dry season.

All proposed plans for the canal involve the use of Lake Nicaragua as part of the sailing course, and the conversion of a portion of the San Juan river and of the canal through the Western Divide cut, into arms of the lake. A course of about twelve miles in the present lake will require deepening, about thirty miles of river will require dredging, and nine miles of heavy excavation will be made on the west side to provide for a sufficient depth for navigation, below the minimum level to which the lake will be permitted to go. Every foot that the elevation of the summit level is allowed to decline, therefore, involves a foot of excavation or dredging through about fifty miles of canal, and the financial inducements are strong for holding the minimum as high as practicable. On the other hand there is an upper limit to the height that the lake surface may be allowed to attain, beyond which great damage will be done to the lands and settlements around the lake. Thus it is necessary to assign definite limits as narrow as practicable between which the lake is to be held.

From evidence of the inhabitants of Granada it is deduced that the highest point the lake has reached during the past forty years is nearly 111 feet above sea level. From evidence of citizens at San Ubaldo it was learned that the lake reached a maximum of about 107.5 in 1893. This is probably the highest point the lake has reached since the Rivas rainfall record began, in 1880. The year 1897 shows a rainfall of 123 inches, as against 105 for 1893; but the lake did not in 1897 reach as high a point as in 1893. The cause is to be found in the state of the lake at the opening of the rainy season. That of 1897 found the lake at the lowest point it had been known recently, caused by a succession of three years with rainfalls 18 to 30 inches below the mean, while 1893 was preceded by a rainfall for 1892 over ten inches above the mean, and for 1891 slightly below, so that the lake must have been somewhere about its normal stage. The rainfall record does not indicate any likelihood that the lake reached any stage higher than that of 1893.

It may be said, therefore, that the lake has been known to rise to an elevation of nearly 111, but that ordinary wet years it does not reach 108.

The rise of 111 inundated considerable improved property, and submerged large areas of land which at present is unused except for pasturage. As the water reaches that point but once in more than a generation or perhaps in a century it could not be allowed to rise so high every year without involving heavy damages. It is somewhat difficult to determine with present

information just how high it would be advisable to allow the lake to rise every year, but it certainly ought not to be higher than 110. This would inundate some land of value at Granada, and large areas along the east and south of the lake, which, though having no present value, are susceptible of cultivation and improvement, but it would avoid any heavy bills for damages to property. The construction of the canal on a plan contemplating inundation to 110, would not prevent deepening at any future time that it is desired to reclaim submerged land. For present purposes we assume the maximum limit as 110.

In fixing the lower limit it is necessary first to examine the conditions of water supply. If there is any considerable period during which the inflow is less than the evaporation, water must be stored to compensate for the loss, to preserve the required depth for navigation.

Amount of Storage Necessary.

To determine the inflow, measurements were made during the dry season of 1898, with a result showing that only two streams were bringing any considerable quantity of water into the lake, and that the total inflow was about 10 per cent. of the evaporation taking place at the same time. Nearly all the streams inspected showed evidences of having been stagnant a long time, the water being foul and dark-colored, with much vegetation growing upon it, which, not being rooted to the soil, would have passed out into the lake, had there been any considerable current. If this condition existed in 1898, a year of more than average rainfall, there must be several months during ordinary years which furnish very little water to the lake. The rainy season usually closes some time in December, the mean rainfall during that month at Rivas being only 1.29 inches. In 1898 the rainy season began about the middle of May, which is understood to be about the normal time. This is well shown, in the diagram, Plate XV. It may be said in general that the rainy season is slightly longer than the dry season, but in years of minimum rainfall this relation is reversed. The maximum evaporation in the dry season is over 6 inches per month; in the rainy season it is much less, and in the early part of the dry season is probably less than 6 inches. It may be assumed that for some time after the close of the rainy season the inflow to the lake will continue equal to or greater than the evaporation. It certainly would not be extravagant to assume that there are four months in which evaporation exceeds the inflow by an average of six inches per month. In other words, for the normal dry season we should provide two feet in depth of storage to make good the ravages of evaporation, and if 105 is to be adopted as the minimum summit level to be allowed, the elevation of the lake at the beginning of the dry season should not be less than 107.

This provision against evaporation might be sufficient if we could be sure that in any cycle of twelve months the inflow to the lake was greater than the evaporation during the same twelve months, but unfortunately no such assurance can be given. While the mean annual rainfall in the basin is much greater than the evaporation, as proved both by the measured quantities of evaporation and rainfall, and by the fact that water is always being discharged through the San Juan river, there is in this basin, as in all other regions, a disparity in precipitation between the dryest and the wettest year which forbids the consideration of averages in any such problem. For purposes of storage against evaporation we must consider the years of minimum inflow and maximum evaporation.

DAM SITE AT TIPITAPA, IN DRY SEASON.

For purposes of computing spillway capacity we must consider years of maximum inflow coincident with minimum evaporation. The data on this point consist of a series of rainfall observations at Rivas, extending from January, 1880, to October, 1898, reported by Dr. Earl Flint, and the short records taken by the Commission.

The year of minimum rainfall shown by the record at Rivas, is 1890, in which 31.81 inches fell. The rainy season in 1898 began about the middle of May. During May and June of this year 35.12 inches of rain fell at Rivas, or 3.31 inches in excess of the total for 1890. The amount of water received by Lake Nicaragua from May 15 to June 30 in excess of evaporation was about sufficient to raise the lake two feet. If the evaporation in this time be taken as 8 inches we have a gross inflow of 2 feet and 8 inches, as the yield of the basin for this rainfall. The run-off of the given precipitation is much greater when concentrated within the period of 45 days than it would have been if distributed over a period of six months, but on the other hand, if no rain had fallen during July, a considerable quantity of water would doubtless have flowed into the lake, as the result of June precipitation. This would probably more than compensate for the excess due to the concentration of the rainfall above mentioned, and to the fact that 35.12 inches exceeds the rainfall of 1890 by over three inches. Suppose we allow four inches depth for the July run-off due to June rainfall. We have, then, as the run-off for the May and June rainfall sufficient water to raise the lake three feet, if it had been isolated and evaporation eliminated. The evaporation during a dry year could not be much below 60 inches; this leaves a deficit of two feet, which, under the above assumption, the minimum year would have wanted of supplying sufficient water to compensate for evaporation. The year 1885 shows a rainfall of 34.59 inches, so that the year 1890, though the minimum in the record, is not an especially anomalous case, and other years of as small or even smaller rainfall should be expected and provided for.

The mean rainfall on the lake surface, taking the records of Las Lajas, San Carlos, Tipitapa and San Ubaldo, is 23.18 inches during this time, made up as follows:

San Carlos	21.08
Las Lajas	23.93
Tipitapa	25.44
San Ubaldo	22.25
Mean	23.18

None of these records show as great a rainfall as that reported for Rivas, by about ten inches. This is the more remarkable as the station at Las Lajas is hardly seven miles from Rivas.

The conditions at Rivas may have been local and anomalous, and the conclusions drawn from the above estimate cannot be considered as final, but they are sufficient to indicate that the adequacy of the annual water supply is at least doubtful.

To approach the problem from the other side, suppose the mean rainfall for the basin of Lake Nicaragua for the minimum year to be two feet. This, if all held and evaporation eliminated, would raise the lake two feet by precipitation directly upon it. To this should be added the probable run-off from the drainage area, but in this we should not include the drainage of Lake Managua. It is said that at times this lake contributes no water to Lake Nicaragua for several years, and there certainly must be years when its contribution is so low that we should not consider it in an estimate of this kind. Taking the area directly tributary to Lake Nicaragua as

6000 square miles and the run-off for two feet of rainfall at 25 per cent., the lake would receive sufficient water from its tributary area to raise it one foot, which, added to that falling directly upon the lake, gives us three feet as the total yield of two feet of rainfall, which agrees with the estimate deduced from recorded observations on the lake, and leaves a deficit of two feet.

Since a year is likely to occur in which evaporation and use exceed the inflow by two feet, that year must be commenced with a water level two feet above the minimum elevation which is to be permitted. As it is impossible at present, and will always be impossible, to predict just when that year of minimum inflow and maximum evaporation is likely to occur, the effort should always be to maintain the summit level at two feet above the minimum. To reach a conclusion as to the elevation at which the lake surface should be held at any given time in order to insure against its decline below the minimum level, let us assume a state of climate in which the inflow is always greater than the evaporation during any twelve months. As above stated, the evaporation in excess of inflow in the normal dry season is estimated at two feet. It would be necessary, therefore, at the end of each rainy season to hold the summit level two feet above the minimum summit level. If this be 105 then the rule would be to enter the dry season with the level at 107, the estimate being that by the time rains begin in May this surplus water would be evaporated and the summit level would stand at 105. Now suppose that in the ensuing year the evaporation and leakage should exceed the inflow by two feet, the natural decline in summit level would bring it down to 103, and to avoid this state of affairs the lake should be held at the opening of the dry season not at 107 but at 109. The indications are, therefore, that the minimum range within which the lake can be controlled, having regard to evaporation only, is not less than four feet.

Spillway Capacity.

As nearly as can be determined by the observations at hand, the maximum rise in the lake in 48 hours, if all had been held, was about .44 of a foot. This indicates an inflow of about 220,000 cubic feet per second. It would be neither necessary nor economical to provide a spillway of this capacity, but would be far cheaper to allow temporary storage for such floods as this and others somewhat greater. Five-tenths of a foot is therefore allowed, which is to be subtracted at the outset from the limit assigned for the control of the lake in any given season.

If the limits set be 105 minimum and 110 maximum, and we deduct two feet from the lower limit as being a permanent reserve against an unusually dry year, and .5 foot from the upper limit for sudden inflow as herein described, we have as a spillway problem the control of the inflow of the year of maximum rainfall between the limits of 2.5 feet.

In attempting to deduce the necessary capacity of a spillway to discharge the surplus water flowing into Lake Nicaragua, we have recourse to the comparison of the observations taken in 1898 with the long record of rainfall at Rivas. This record indicates that the maximum annual precipitation in 19 years was for the year 1897, 123.43 inches. Comparing the record at the same place for 1898, up to October 31, with that for the corresponding months of 1897 we find that the precipitation for 1898 is 83 per cent of that for 1897. In other words, the precipitation for 1898 should be increased

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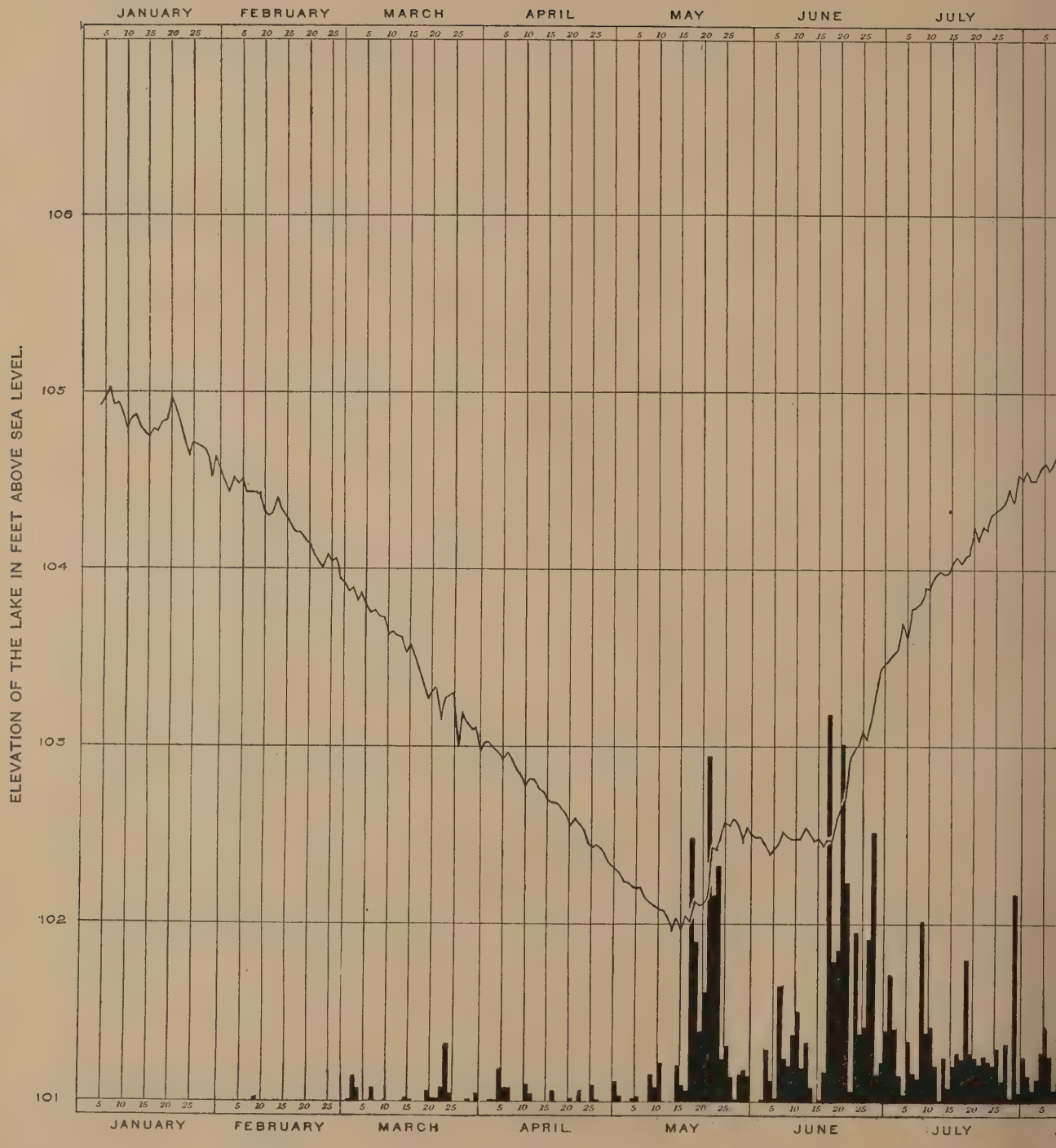
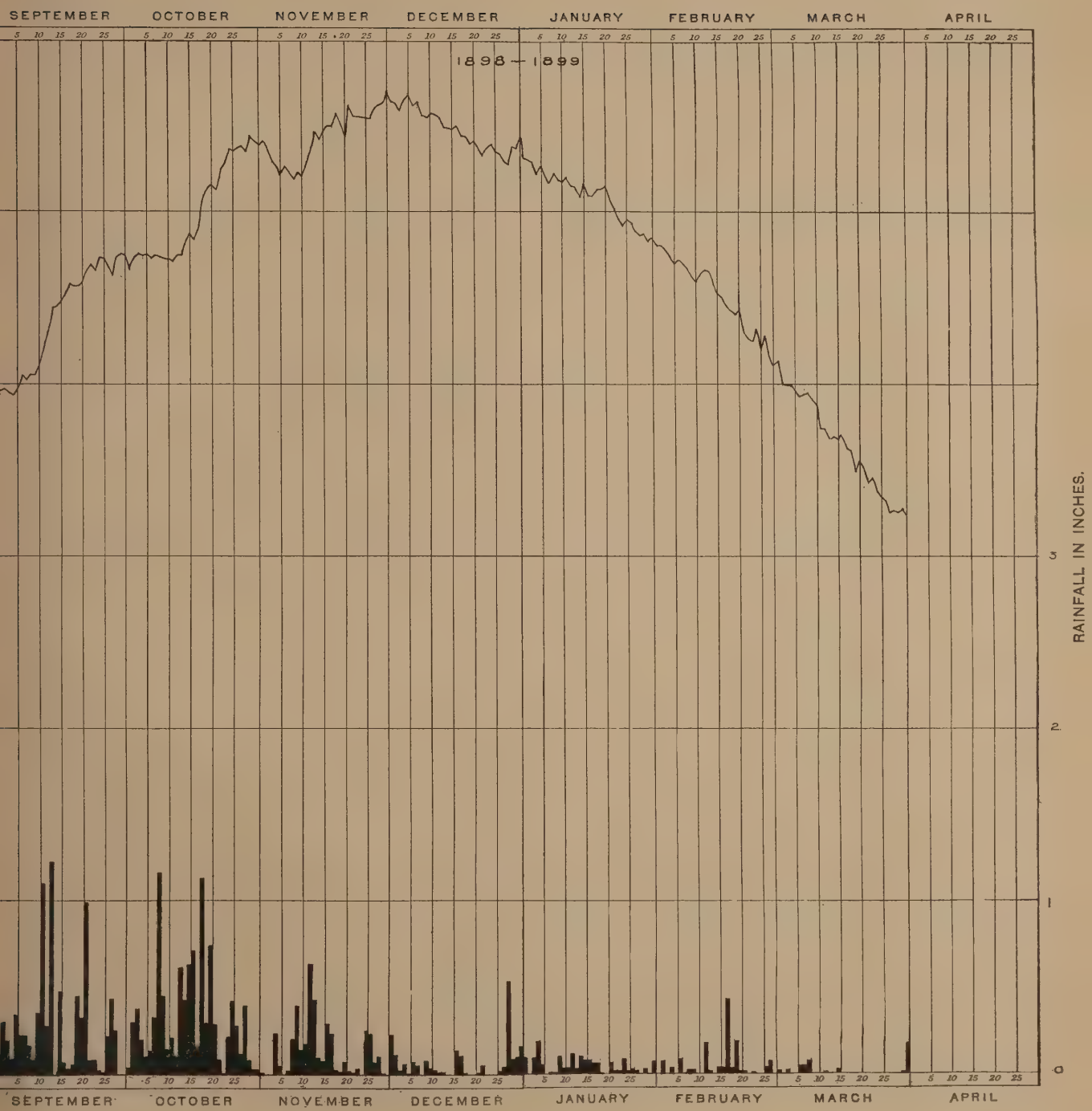


DIAGRAM OF THE DAILY MEAN ELEVATION OF LAKE



COMPARED WITH THE SYNCHRONOUS RAINFALL IN ITS BASIN.

21 per cent. to be equal to that of the maximum in the record. While we have no conclusive data upon which to estimate the percentage of run-off to rainfall in the basin of Lake Nicaragua, yet it is well established as a general rule that in any given basin the greater the rainfall in a given time, the greater the percentage of run-off, so that if the rainfall were increased 21 per cent. the run-off should be increased somewhat more, say 25 per cent. Now the run-off for the basin of Lake Nicaragua has been measured for 1898 up to the 27th day of October. From June 15 to October 27 the lake received in excess of evaporation 13,450,000 acre-feet of water, 5,450,000 of which were discharged through the San Juan river and 8,000,000 were stored in the lake. This is equivalent to a mean inflow in excess of evaporation of 50,700 cubic feet per second. If this inflow be increased by 25 per cent. to make it correspond with that of the hypothetical maximum year we have a mean influx of 63,375 cubic feet per second, which if continued for 183 days would have contributed a total of 23,005,400 acre-feet. If we limit the rise in the lake during this time to 2.5 feet we find the required spillway capacity to be 49,680 cubic feet per second. It seems, therefore, that a spillway capacity of 50,000 cubic feet per second would have kept the lake within the desired limit during the year of maximum rainfall as above computed. Under the same conditions, the rise could have been limited to 1.5 by a spillway of 56,000 cubic feet capacity.

The question now arises whether there is any reason to believe that rainfall during the maximum year is likely to be so concentrated within a short period as to be greater than the capacity of our spillway to care for. Our only recourse is to the rainfall observations during the maximum year. Here we find that during October, 1897, 33.85 inches of rain fell, which is more than one-fourth of the total for that year and exceeds by nearly 50 per cent. the precipitation for any other one month in the entire record of 19 years. Such a rainfall coming near the close of the rainy season when Lake Managua and tributary streams are full and the ground is generally saturated, might, it seems, well be taken as the most unfavorable condition likely to occur. An examination, therefore, of the results which would have followed such a year as 1897, with our estimated spillway capacity under perfect control, should indicate whether or not our works or property on the lake would have been damaged in that maximum year.

The inflow to Lake Nicaragua between May 15 and September 30 was 12,525,000 acre-feet in excess of evaporation. The rainfall during these months was exceeded by that in the corresponding months of 1897 by about 10 per cent. The corresponding run-off for 1897 would, therefore, have exceeded that for 1898 by a somewhat larger percentage, say 12 per cent. This would give an inflow for 1897 up to the 30th of September of 14,028,000 acre-feet. This is equivalent to a mean inflow of about 51,000 cubic feet per second. A spillway of 50,000 cubic feet per second discharging all the time would have confined the rise to .28 foot; then we still have a limit of 2.2 feet which the lake can rise during October before reaching the danger line. During May and June, 1898, 35.12 inches of rain fell at Rivas and the inflow was about 4,000,000 acre-feet, exclusive of evaporation. The rainfall during October, 1897, was 33.85 inches, or 1.27 less than during May and June, 1898. The run-off, however, would have been greater owing to the fact that the rain for May and June fell upon dry land and was

largely absorbed, and Lake Managua and its drainage area contributed practically nothing to Lake Nicaragua during that time, while in 1898 Lake Managua contributed during October a total of nearly 250,000 acre-feet, and the same influence would have operated in a less degree to increase the inflow from all tributaries of Lake Nicaragua during October over what it was during May and June. Making due allowance for the lesser rainfall in October and the greater proportional run-off, it would seem that to allow ten per cent. increased inflow over that for May and June, 1898, would be sufficient, and this would just bring the lake to 109.5; and for the spillway capacity to prevent further rise we must assume the inflow to be no greater than 50,000 cubic feet per second. As the Rivas rainfall for November, 1897, is but 5.15 inches, and exceeds the mean for that month by about 14 per cent., this seems to be a safe assumption.

It will be observed, however, that this presupposes the opening of the spillway to its full capacity throughout the season, allowing the lake to rise less than .3 foot. But it must be borne in mind that the heavy rainfall for October could not be predicted for any specific year, and as it is necessary to hold the lake at 109 at the end of the rainy season, as above indicated, it would not be safe to permit the level to remain so low at the end of September, unless the rainfall after that date can be depended upon to supply the necessary storage, namely, 1.7 feet. The smallest rainfall in the record for October, November and December, in any one year, is that for 1895, when 11.21 inches fell, which it seems by comparison with this year's record would have raised the lake about a foot. The run-off due to previous rainfall would have been considerable, at least .2 foot, so that we would lack .5 foot of having the desired reserve storage, and it would be necessary to begin October with a lake level not lower than 107.8. The year of heavy rainfall according to the above estimates, would have carried the level to just 110, the extreme limit.

In view of the fact that such extreme conditions as we have been assuming occur very seldom, and that the lake has risen in past years above 110 from natural causes, an error of judgment in the manipulation of the spillway which should allow the surface to rise a few inches above the limit set, could not be regarded as doing more than repeating the results of nature.

Value of the Estimates.

The data upon which the above estimates are necessarily made are meager, and it becomes important to form an idea as definite as may be regarding their value.

The extensive use which is made of the record of Rivas rainfall involves to an important degree the question of the probable integrity and reliability of that record. The observations were taken by, or under the authority of, Dr. Earl Flint, a thoroughly competent observer, and the record in itself contains no indication of being faulty. While the range between maximum and minimum rainfall might appear to be large, it is not so large in percentage as in many records taken in the United States. Without further evidence pro or con the record might be considered good, at least as good as rainfall records usually are. A comparison of the records at Rivas and at Masaya and Granada shown in diagram (Fig. 8) exhibits a striking parallelism with no discrepancies greater than might be expected from stations located relatively as these are. The somewhat surprising fact that the rainfall observed at Rivas for 1898 is much greater than that at any of the stations main-

NICARAGUA CANAL COMMISSION

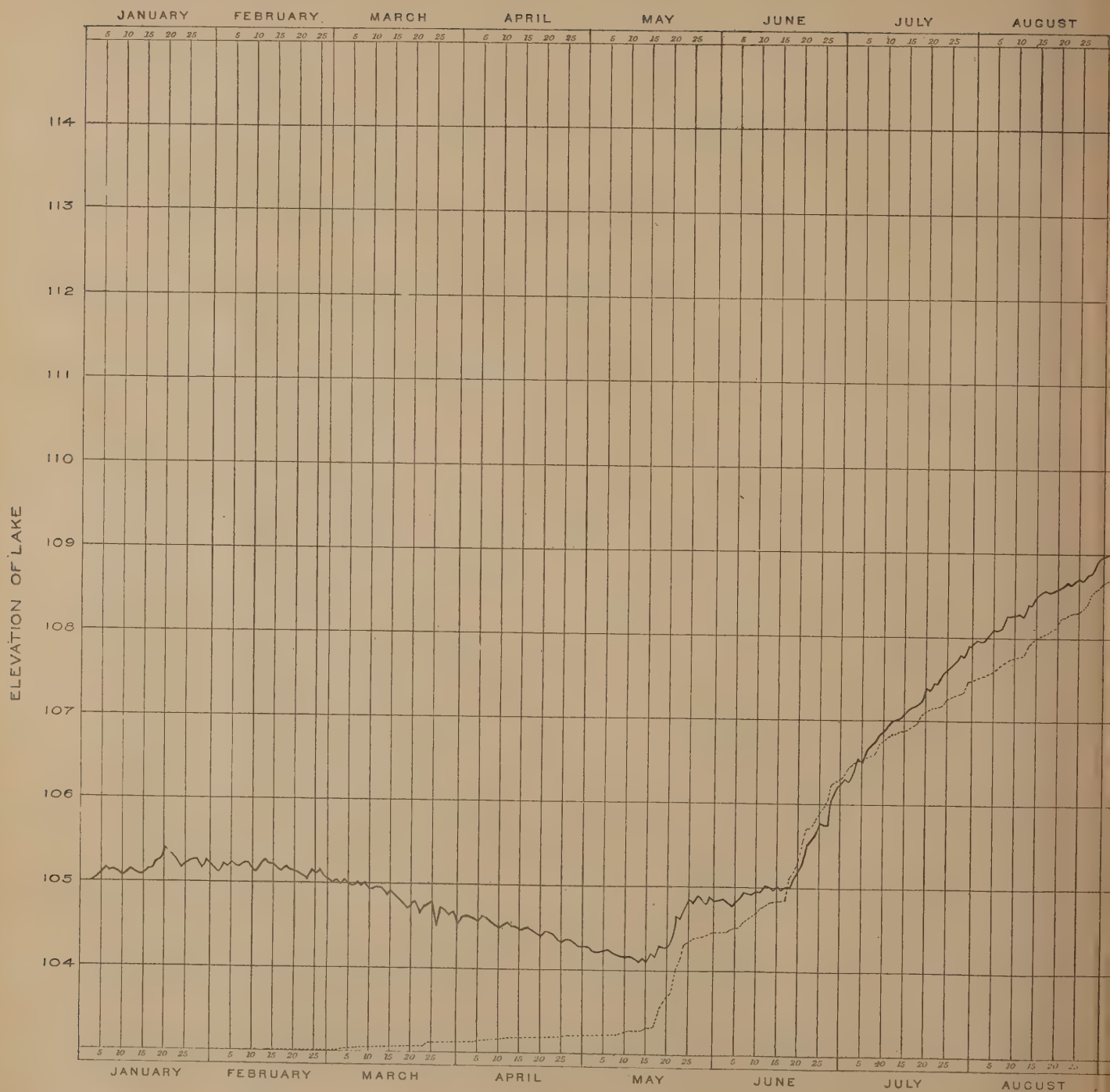
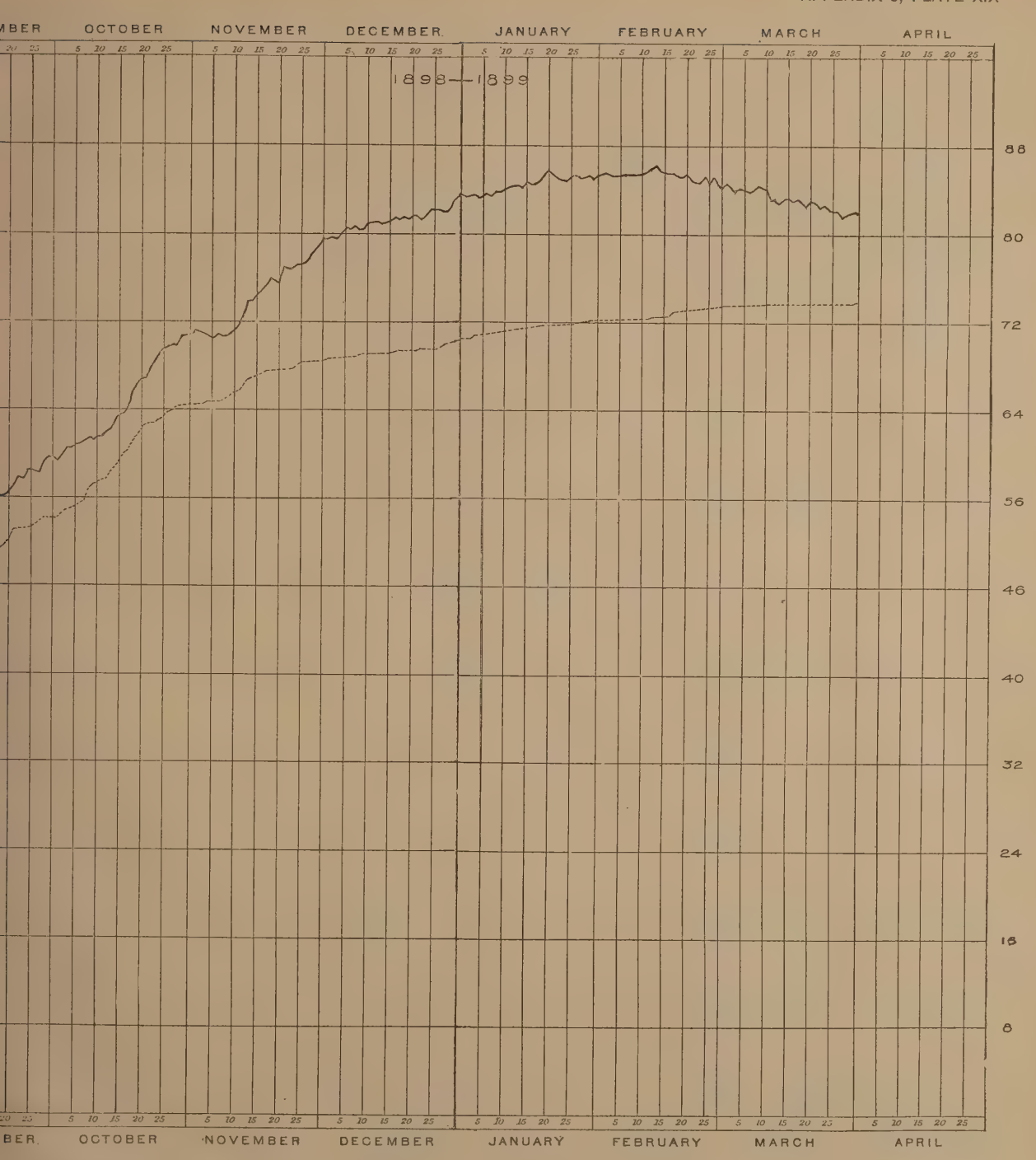


DIAGRAM OF THE DAILY MEAN INFLOW TO LAKE NICARAGUA COMPARED WITH THE MEAN RAINFALL IN ITS B

THE DOTTED LINE INDICATES TH



HE CONTINUOUS LINE INDICATES THE ELEVATION OF THE LAKE IF ALL WATER HAD BEEN HELD.
MULATED RAINFALL.

tained by this Commission in the vicinity, also appears in the diagram, which shows that it is also greater than that taken at Masaya and Granada, in nearly every year of the record. The inference, therefore, is that from natural causes the rainfall at Rivas actually is greater than in most other parts of the basin, due probably to local meteorologic conditions, but these local conditions do not vitiate the record as a means of comparison, because, as the diagram indicates, they still bear a reasonably uniform relation to the stations of lesser rainfall. It would appear, therefore, from all the evidence at hand, that the Rivas record may be used as safely and within as wide limits as any rainfall record can be. It must be admitted, however, that fluctuations of rainfall, local and spasmodic, occur in all parts of the world, and if our estimates depended absolutely upon the reliability of the assumption that the Rivas rainfall bears a fixed relation to that of the entire basin, the results could not be relied upon within narrow limits. The problem presented, however, is of such a character that the conclusion may be relied upon within very much narrower limits than the probable error of individual estimates. The estimates for spillway depend upon the assumption that the relation of the rainfall for 1898, for which we have a measured run-off, and the rainfall for 1897 is the relation indicated by the Rivas record. If from temporary causes the Rivas record for 1898 is too large, then its assumed relation to the maximum year is too large, and we will have greater floods than those estimated and will need either a wider limit of fluctuation in the lake or greater capacity of spillway. But under the same supposition we have also estimated too small a rainfall for the

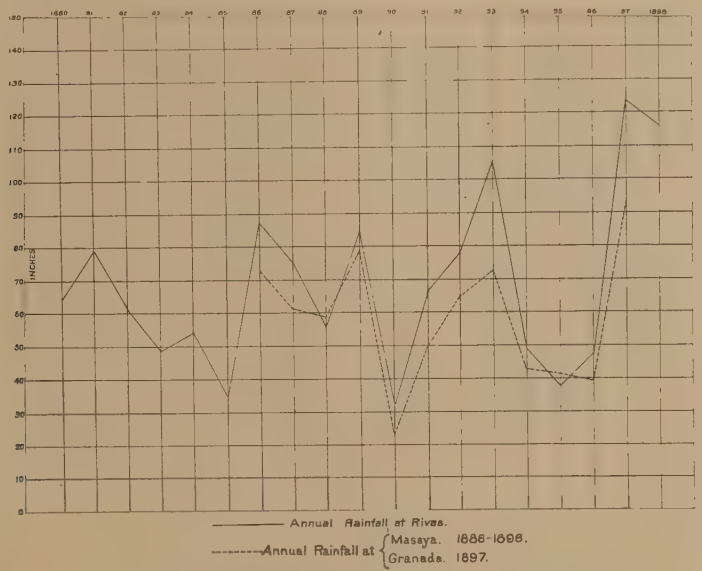


FIG. 8. Comparative rainfall at Rivas and Masaya.

dry years and the provision for storage against such years is estimated too large. Here, then, we have two errors which tend to counterbalance each other. Conversely, if from temporary causes the rainfall at Rivas was abnormally small, we have the reverse result in both cases, but still the two errors tend to counterbalance each other, and it is believed that the facts known are sufficient to indicate with all necessary accuracy the limits within which the lake can be controlled, and the spillway capacity necessary for the purpose.

The conclusion, therefore, is that the lake can probably be controlled within limits of five feet, if an adjustable spillway be provided with a capacity of 50,000 cubic feet per second. The excavation required, however, is such that if the limit could be reduced to four feet, it would save one foot of excavation throughout a large part of the summit level, and reduce the cost more than two million dollars.

If a range of fluctuation be allowed greater than five feet, the spillway capacity may be reduced and the supply for dry seasons will be made more secure.

Lake Managua.

It has been suggested that Lake Managua might be utilized as a reservoir in which to store a portion of the water required, at a less cost than it could be stored in Lake Nicaragua. This lake lies to the north and west of Lake Nicaragua, has a surface of about 438 square miles and a tributary drainage area of about 2500 square miles. Its surplus waters are discharged into Lake Nicaragua by way of Tipitapa river. One mile below the point where this river leaves Lake Managua, it falls over a cataract descending about 13 feet in a horizontal distance of 500 feet. It is estimated that a dam might be constructed at this point, and the waters of Lake Managua raised about eight feet above the surface of the rock at the falls without serious damage to property around the margin of the lake. An outlet tunnel or cut might be provided to draw off the water to the level of the river below the falls. All these works would be inexpensive and a storage capacity would thus be secured for a depth of 20 feet over the entire surface of Lake Managua, which, if drawn off in its entirety would raise Lake Nicaragua about three feet. To further test the merit of this proposition, measurements of rainfall and outflow were made at Tipitapa and a station was established on Rio Viejo about 50 miles north of the lake for the measurement of rainfall and of the discharge of the principal tributary to Lake Managua, Rio Viejo; also to obtain data regarding the regimen and discharge of Rio Nueva.

The cost of utilizing Lake Managua as a storage reservoir for the summit level would be roughly about as follows:

Cost of overflow ogee dam at Tipitapa	
1600 yds. concrete at $15	$24,000
Excavation of outlet	20,000
Gates and gatehouse	6,000
	$50,000
Diversion of Nueva:	
750,000 cubic yards earth at 20 cents.	$150,000
Dam	100,000
Total	$300,000

So far as works are concerned, this project is practicable and cheap, but the water supply is doubtful. It is known that entire years sometimes occur in which there is no outflow from the lake, but on the other hand, the fact that water does often flow out proves beyond question that

in the long run, the inflow exceeds the evaporation and seepage from the lake.

The discharge from Lake Managua has been measured for the year 1898, excepting for the months of January and December. Estimating the discharge for these two months, we have a total outflow for the year of something over 1,100,000 acre-feet, or enough to raise Lake Nicaragua .55 foot, or to raise Lake Managua 3.8 feet, if all had been held.

Had Rio Nueva been diverted into Lake Managua during this year, as suggested on page 208, it would have contributed about 200,000 acre-feet more, sufficient in all to have raised Lake Managua about 4½ feet in excess of evaporation, or enough to raise Lake Nicaragua eight inches. Though the precipitation and run-off of 1898 were probably above the average, still it would be fair to expect one or more such years in each interval between the years of drought, and to assume that the inflow to Lake Managua during the other years would on an average be equal to the evaporation. If this assumption be correct, we have for $300,000 a storage that would cost over one million dollars to provide in Lake Nicaragua. The information at hand is not sufficient to admit any conclusion as to the actual quantity of practicable storage, but if in each year of extreme drought Lake Managua could furnish an amount of water equal to 18 inches over its own surface, its storage would be cheaper than the same storage capacity provided by excavation along the canal line. It seems entirely safe to conclude that this could be done. The storage of water in Lake Managua would also assist in the control of the surplus waters by reducing the area of the watershed to be provided for.

Sediment Observations.

Any proposition for a ship canal which involves the use of the San Juan river below the mouth of the San Carlos requires for its intelligent consideration some idea of the quantity of sediment carried by that stream, and if the San Juan is to be used below the mouth of the Sarapiqui the sediment carried by that stream becomes also an important factor. To determine these quantities samples of water were taken daily, allowed to settle, and the sediment measured. The samples were taken at not less than a dozen places in the river, the water taken aggregating several gallons, and representing approximately the average of the various parts of the current. The samples were thoroughly mixed, and one sample of 100 cubic centimeters taken from the mixture, and the rest rejected. The sample taken was allowed to settle for 24 hours, the clear water poured off, and another sample added to the remainder, the clear water was decanted the next day, another sample added, and so on, accumulating any sediment that remained, until it became a measurable quantity, when its depth was read on the graduated glass in which the settlement was made. This reading gives, of course, only the bulk of the loose mud, and not the dry solid matter.

SEDIMENT BY WATER-SAMPLES FROM SAN CARLOS RIVER, 1898.

Month.	Mud.	Solid Matter.	Remarks.
	Cubic yards.	Cubic yards.	
June	705,000	141,000	5 cu. yds. mud are assumed equal to
July	1,636,000	327,200	1 cu. yd. of solid matter.
August	778,250	155,650	

The relation between the mud and dry matter as determined by a series of experiments for a similar purpose made on sediment from the Gila river, Arizona, was five parts of mud to one of dry material. This factor has, therefore, been used in reducing the results.

The taking of water samples and measurement of sediment therein would not furnish all the required data, as these streams roll large quantities of sand and gravel along their beds, which could not be taken in water samples. So far as could be learned no attempt at such measurements had ever been made, and it was recognized as a task of difficulty. The method devised was as follows:

A galvanized sheet-iron pan was provided (see Fig. 9), one meter square and eight inches deep, with one side hinged so that it could be opened to lie in the same plane as the bottom of the pan, and a weight and stays were provided to hold it in this horizontal position. Four chains, attached one to each corner of the top of the pan, met about four feet above the pan, and united in a ring, and the whole was suspended from a cable stretched across the river, with the door open upstream. An anchor was thrown about 100 feet upstream to hold the pan firmly in position, while it was gently lowered from the cable by means of a rope from shore, working in tackle blocks. The pan was allowed to settle firmly on the bottom, and to remain for a limited time, usually one hour. The attempt is to cause the minimum disturbance of natural conditions in the stream, and to intercept and hold in the pan the sediment traveling along the bottom in the section it occupies. When it is desired to close the observation, a small copper wire which has been fastened to the open door and passed through the ring above the pan, is stoutly pulled until it raises the lid from the bottom of the stream, whereupon the current catches and slams the lid shut, where it is automatically fastened by a latch on each side. Then, by means of a windlass on shore, the pan is hoisted and brought to land, and the entrapped sediment measured.

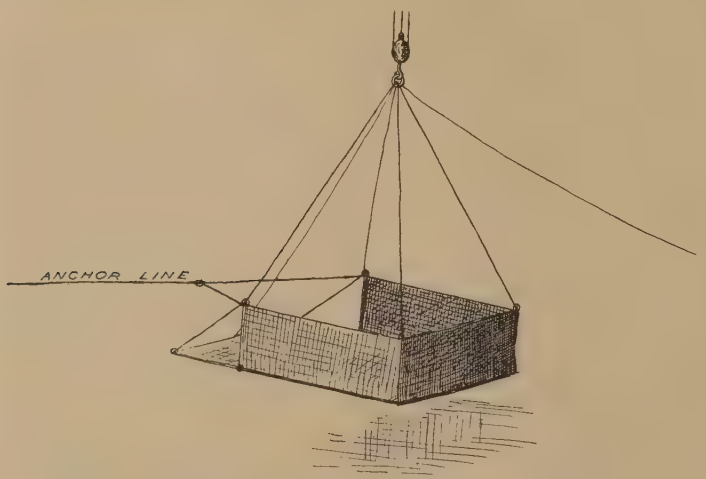


FIG. 9. The Sediment Trap ready for use.

There is nothing about this operation to in-

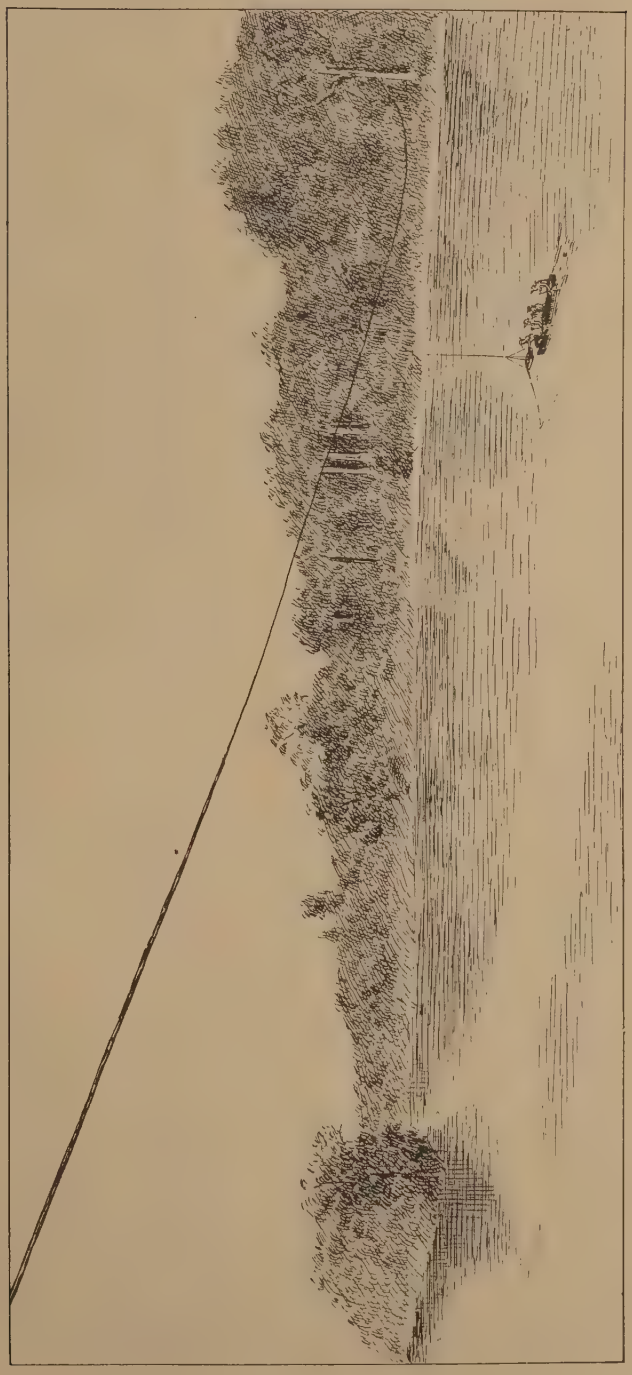


PLATE XX. Measuring the sediment.

crease the motion of sediment along the bottom into the pan, so it is thought that results can never be too large. On the other hand some sand may pass under the edge of the lid, when the bottom of the river at this point is marred with local inequalities. This is supposed to be one cause of the small results on certain days, when other observations immediately before or after, give large results. Another persistent source of error of unknown magnitude is the washing out of the sediment by the current over the weir formed by the back of the pan. To test the importance of this theoretical possibility, a temporary partition was placed in the pan, perpendicular to the current, and nearly as high as the sides of the pan, the theory being that if all sediment were stopped by the partition and deposited in front of it, that would be good evidence that in the absence of the partition all would be stopped by the back of the pan, and none lost. In the first experiment more sediment was deposited behind than in front of the partition, and the quantity that passed out of the pan is unknown. This result was essentially repeated for most of the experiments, showing conclusively that more or less sediment is carried out over the back of the pan by the scour which it occasions. It is important to bear this fact in mind, when studying the results, for it is certain that the results are quantitatively too small, and should be regarded as showing that large quantities of sediment are traveling on the bed of the stream, and as roughly indicating the relative amount.

SEDIMENT ROLLED ON BOTTOM OF SAN CARLOS RIVER, COSTA RICA.

Date.	Gage height.	Amt. collected per hr. in c. c.	Total for river in cu. yds. per hour.	Mean for month in cu. yds. per hour.	Total cu. yds. per month.	Remarks.
Mar. 29, 1898.	12.00	21,450	5.61	5.61	4,174	Coarse sand
April 27.....	11.34	46,610	12.19	12.91	9,295	
May 3.....	11.03	18,650	4.88	.....	.....	" "
" 19.....	12.05	31,475	8.23	.....	.....	" "
" 24.....	12.10	14,000	3.66	5.59	4,159	" "
June 15.....	12.60	16,040	19.90	.....	.....	" "
" 17.....	13.50	12,400	3.24	.....	.....	Gravel and sand
" 20.....	14.40	12,400	3.24	.....	.....	Coarse sand
" 30.....	15.53	64,340	16.82	10.80	7,776	Gravel and sand
July 14.....	14.93	35,300	9.23	.....	.....	" "
" 15.....	14.50	25,700	6.72	.....	.....	" "
" 16.....	14.30	20,600	5.39	.....	.....	" "
" 16.....	14.80	21,800	5.70	.....	.....	" "
" 19.....	14.10	21,000	5.50	.....	.....	" "
" 20	14.20	23,900	6.25	.....	.....	" "
" 26.....	13.20	26,460	6.92	.....	.....	" "
" 26.....	13.10	23,780	6.22	.....	.....	" "
" 27.....	13.00	46,400	12.13	.....	.....	" "
" 27.....	13.10	48,625	12.71	7.68	5,714	" "
Aug. 9.....	13.30	21,300	5.57	.....	.....	" "
" 10.....	13.20	31,100	8.13	.....	.....	" "
" 10.....	13.10	88,210	23.07	.....	.....	" "
" 11.....	13.45	106,740	27.91	.....	.....	" "
" 11.....	13.60	59,230	15.48	16.03	11,926	" "
Oct. 8.....	13.10	39,300	10.27	.....	.....	" "
" 20.....	15.90	53,000	13.86	.....	.....	" "
" 22.....	14.35	102,062	26.69	.....	.....	" "
" 29.....	14.83	87,950	22.87	18.42	13,704	" "
Nov. 4.....	14.00	34,500	9.70	.....	.....	Fine sand and pebbles.
" 5.....	13.50	30,965	8.10	.....	.....	Fine and coarse sand.
" 21.....	15.00	121,500	33.30	.....	.....	Coarse sand and gravel.
" 22.....	14.70	32,270	8.80	.....	.....	" "
" 23.....	14.30	115,340	31.60	18.30	13,180	" "
Dec. 2.....	13.60	52,950	13.80	.....	.....	
" 6.....	13.90	112,150	29.50	.....	.....	
" 15.....	13.55	38,190	10.00	.....	.....	

SEDIMENT ROLLED ON BOTTOM OF SAN CARLOS RIVER, COSTA RICA.—Continued.

Date.	Gage height.	Amt. collected per hr. in c. c.	Total for river in cu. yds. per hour.	Mean for month in cu. yds. per hour.	Total cu. yds. per month.	Remarks
Dec. 16.....	13.35	62,680	16.40	.....	.....	
" 23.....	12.40	23,070	6.00	15.10	11,230	
Jan. 3, 1899.	13.80	27,702	7.30	.....	.....	
" 9.....	12.50	22,368	5.85	.....	.....	
" 19.....	13.20	92,272	24.10	.....	.....	
" 23.....	12.50	64,704	16.90	.....	...	
" 27.....	12.20	90,450	23.65	.....	.....	
" 28.....	12.15	137,250	35.90	18.95	14,100	
Feb. 9.....	11.69	31,002	8.10	.....	.....	
" 23.....	13.55	5,434	1.40	4.75	3,190	
Mar. 10.....	12.15	7,034	1.85	.....	.....	
" 20.....	11.40	58,250	15.25	.....	.....	
" 24.....	11.20	152,420	39.85	18.98	14,120	

SEDIMENT ROLLED ON BOTTOM OF RIO SARAPIQUI.

Date.	Gage height.	Amt. collected per hour in c. c.	Total for river in cu. yds. per hour.	Mean for month.	Total for month in cu. yds.	Remarks.
Sept. 1, 1898.	7.95	11,000	1.44	.....	.....	Sediment is invariably
" 5.....	8.22	5,000	.66	.....	.....	composed of black sand
" 6.....	8.38	5,000	.66	.....	.....	with occasional gravel.
" 19.....	8.79	29,000	3.80	.....	.....	
" 20.....	8.70	15,000	1.96	.....	.....	
" 26.....	9.46	15,750	2.05	1.76	1,270	
Oct. 4.....	8.46	16,500	2.16	.....	.....	
" 12.....	10.50	22,500	2.95	.....	.....	
" 18.....	11.65	49,300	6.45	.....	.....	
" 20.....	11.50	41,700	5.46	.....	.....	
" 21.....	10.65	32,500	4.26	.....	.....	
" 25.....	10.50	26,000	3.41	.....	.....	
" 28.....	10.10	25,250	3.31	4.00	2,976	
Nov. 1.....	9.22	32,000	4.20	.....	.....	
" 2.....	8.75	29,000	3.80	.....	.....	
" 3.....	8.55	21,000	2.70	.....	.....	
" 4.....	9.30	45,600	5.95	.....	.....	
" 5.....	8.90	28,000	3.70	.....	.....	
" 11.....	12.10	42,000	5.50	.....	.....	
" 12.....	11.20	22,000	2.90	.....	.....	
" 22.....	11.00	148,000	19.40	.....	.....	
" 23.....	10.30	76,000	10.00	.....	.....	
" 24.....	9.90	31,000	4.05	.....	.....	
" 26.....	9.80	57,000	7.50	.....	.....	
" 28.....	10.05	22,500	3.00	6.06	4,360	
Dec. 1.....	9.70	88,000	11.50	.....	.....	Sand.
" 3.....	11.30	188,000	24.60	.....	.....	"
" 5.....	10.80	122,000	16.00	.....	.....	"
" 12.....	11.95	69,400	9.10	.....	.....	"
" 14.....	10.05	55,000	7.20	.....	.....	"
" 15.....	9,48	79,000	10.30	.....	.....	"
" 22.....	7.98	51,000	6.60	12.20	9,080	"
Jan. 2, 1899.	12.14	22,500	2.90	.....	.....	"
" 4.....	8.41	48,000	6.30	.....	.....	"
" 10.....	8.34	76,000	9.90	.....	.....	"
" 17.....	10.70	25,500	3.30	.....	.....	"
" 18.....	9.76	33,500	4.40	.....	.....	Coarse sand and gravel.
" 19.....	10.16	86,000	11.20	.....	.....	" " " "
" 23.....	8.39	40,000	5.20	.....	.....	" " " "
" 24.....	8.46	34,000	4.40	.....	.....	Fine sand and some gravel.
" 26.....	8,30	30,000	3.90	5.72	4,260	Sand.
Feb. 2.....	7.42	10,500	1.40	.....	.....	"
" 6.....	7.72	24,500	3.20	.....	.....	"
" 7.....	7.90	25,000	3.30	.....	.....	"
" 15.....	9.58	24,000	3.10	.....	.....	"
" 18.....	8.46	17,000	2.20	.....	.....	"
" 22.....	9.50	42,500	5.60	.....	.....	"
" 23.....	9.84	11,500	1.50	.....	.....	"
" 28.....	9.36	23,000	3.00	2.91	1,960	"

Temperature and Relative Humidity.

The temperature of Nicaragua is remarkably uniform. While some of the higher mountain regions have a rather cool climate, there is never any frost, and in general it may be said that in the habitable region of the republic the temperature seldom exceeds 90 degrees Fahrenheit or falls below 70, and in any given locality the annual fluctuation is usually still less.

The relative humidity is high in all of the uniformly high temperatures excepting during the dry season on the west side of the isthmus.

Observations of wet and dry bulb thermometers were carried on at the station on the Rio Grande, at Las Lajas, Rio Viejo, Fort San Carlos, Sabalos, Rio San Carlos, Ochoa, Deseado and at Greytown, and the results are given in the following tables:

TEMPERATURE AND RELATIVE HUMIDITY AT BRITO AND TOLA STATIONS, 1898.

Day.	January.			February.			March.			April.		
	Mean temp.	Mean t—t′.	Relative humidity.	Mean temp.	Mean t—t′.	Relative humidity.	Mean temp.	Mean t—t′.	Relative humidity.	Mean temp.	Mean t—t′.	Relative humidity.
1.....	....	....	....	80	7.0	72	80	8.0	68	83	4.0	84
2.....	....	....	....	80	7.5	70	81	7.0	72	84	6.5	75
3.....	....	....	....	78	7.5	70	84	8.0	69	84	8.0	69
4.....	....	....	....	80	7.5	70	84	8.0	69	84	6.5	75
5.....	....	....	....	79	7.5	70	83	8.5	67	85	5.5	78
6.....	....	....	....	81	10.5	60	83	8.5	67	84	6.5	75
7.....	....	....	....	80	8.5	66	81	6.0	76	85	9.5	65
8.....	....	....	....	80	7.5	70	81	7.5	70	86	12.0	57
9.....	....	....	....	79	6.5	74	81	9.5	63	86	10.0	63
10.....	....	....	....	80	5.5	78	82	8.5	67	86	10.5	62
11.....	....	....	....	81	7.5	70	83	8.5	67	84	7.5	71
12.....	....	....	....	81	7.0	72	82	7.5	71	82	7.0	72
13.....	....	....	....	80	7.5	70	83	8.5	67	83	8.5	68
14.....	....	....	....	80	8.0	68	83	8.0	69	83	7.0	73
15.....	....	....	....	80	8.0	68	84	8.5	67	82	7.5	71
16.....	....	....	....	81	7.5	70	83	8.5	67	82	7.5	71
17.....	....	....	....	80	7.5	70	84	9.0	66	82	5.5	78
18.....	....	....	....	81	7.5	70	79	5.5	78	83	7.0	73
19.....	....	....	....	82	7.5	70	82	8.5	66	83	7.5	71
20.....	....	....	....	81	7.0	72	83	9.5	64	83	6.0	76
21.....	....	....	....	82	7.0	72	83	8.5	67	81	4.5	82
22.....	....	....	....	82	8.5	67	84	9.5	64	82	6.0	76
23.....	....	....	....	80	7.5	70	82	8.0	69	83	7.5	71
24.....	79	4.5	81	81	8.0	68	80	3.5	86	84	8.0	69
25.....	79	5.5	77	81	7.0	72	82	6.5	74	83	5.5	78
26.....	78	3.5	85	81	8.5	66	83	5.5	78	82	6.5	74
27.....	80	6.5	74	81	8.0	68	84	8.0	69	83	7.5	71
28.....	80	7.0	72	82	9.5	64	85	7.5	71	84	7.5	71
29.....	81	7.5	70	....	....	....	84	7.5	71	84	7.5	71
30.....	79	7.5	70	....	....	....	82	6.0	76	82	5.5	78
31.....	80	7.5	70	....	....	....	83	4.5	82	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT BRITO AND TOLA STATIONS, 1898.

Day.	MAY.			JUNE.			JULY.			AUGUST.		
	Mean temp.	Mean t—t′.	Relative humidity.	Mean temp.	Mean t—t′.	Relative humidity.	Mean temp.	Mean t—t′.	Relative humidity.	Mean temp.	Mean t—t′.	Relative humidity.
1.....	86	9.0	67	81	2.0	92	76	0.5	98	79	2.5	89
2.....	84	6.5	75	81	2.5	90	78	1.5	94	78	2.5	89
3.....	84	7.5	71	81	2.5	90	78	1.5	94	80	2.5	89
4.....	85	5.5	78	81	3.0	88	79	2.0	91	78	1.5	94
5.....	86	3.5	86	82	2.5	90	80	3.5	85	79	1.5	94
6.....	85	4.5	82	82	3.0	88	80	2.5	89	81	1.5	94
7.....	86	4.5	82	79	0.5	98	78	0.5	98	81	3.0	88
8.....	87	5.5	78	82	2.5	90	78	2.5	89	80	3.0	87
9.....	86	5.0	81	82	2.5	90	78	1.0	96	80	3.5	85
10.....	86	1.0	96	81	2.0	92	77	0.5	98	81	2.0	91
11.....	82	0.5	98	83	4.0	84	78	2.0	92	81	2.5	90
12.....	85	1.5	94	83	8.0	69	78	0.5	98	78	2.5	89
13.....	85	0.5	98	....	...	...	79	1.0	96	78	2.0	91
14.....	86	1.0	96	80	3.5	85	80	1.5	94	76	1.0	96
15.....	85	1.0	96	....	....	....	80	2.5	89	78	2.0	91
16.....	83	3.0	88	....	....	....	76	0.5	98	79	2.0	91
17.....	84	4.0	84	78	1.0	96	79	0.5	98	79	2.5	89
18.....	82	4.0	84	78	1.0	96	80	2.0	92	78	2.0	91
19.....	82	2.5	90	78	0.5	98	78	3.0	87	80	2.0	92
20.....	80	3.0	87	79	0.5	98	78	2.0	91	80	2.0	92
21.....	80	3.0	87	78	1.0	96	79	2.5	89	78	1.5	94
22.....	74	0.5	98	76	0.5	98	79	2.0	91	79	1.5	94
23.....	77	1.0	96	78	1.5	94	80	3.0	87	80	2.5	89
24.....	77	1.5	94	77	1.0	96	79	2.0	91	79	1.5	94
25.....	78	3.5	85	79	1.5	94	80	2.5	89	79	1.0	96
26.....	78	1.5	94	79	1.5	94	78	2.0	91	79	2.0	91
27.....	81	2.0	92	76	0.5	98	77	1.0	96	79	1.5	94
28.....	81	1.0	96	75	0.0	100	78	1.5	94	78	1.5	94
29.....	81	2.0	92	78	2.0	91	80	2.5	89	78	1.5	94
30.....	82	1.5	94	80	2.5	89	76	1.0	96	81	2.5	90
31.....	82	2.5	90	....	....	....	78	1.5	94	80	2.0	92

TEMPERATURE AND RELATIVE HUMIDITY AT BRITO AND TOLA STATIONS, 1898.

Day.	SEPTEMBER.			OCTOBER.		
	Mean Temp.	Mean t—t′.	Relative humidity.	Mean Temp.	Mean t—t′.	Relative humidity.
1.....	78	3.0	87	80	3.5	85
2.....	80	2.5	89	81	3.5	86
3.....	80	3.0	87	81	3.0	88
4.....	81	3.0	88	82	3.0	88
5.....	79	2.0	91	77	1.0	95
6.....	79	1.5	94	81	3.5	86
7.....	80	2.5	89	76	0.5	98
8	80	2.5	89	78	1.0	96
9.....	80	2.0	92	79	1.5	94
10.....	76	1.0	95	78	2.0	91
11.....	79	2.0	91	74	1.0	95
12.....	79	1.5	94	78	1.0	96
13.....	76	1.0	95	77	1.0	95
14.....	76	0.5	98	77	1.0	95
15.....	79	1.5	94	78	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT BRITO AND TOLA STATIONS, 1898.—Continued.

Day.	September.			October.		
	Mean Temp.	Mean t−t′.	Relative humidity.	Mean Temp.	Mean t−t′.	Relative humidity.
16	79	1.0	96	78	1.5	93
17	80	1.5	94	76	0.5	98
18	81	2.0	92	76	0.5	98
19	80	3.0	87	78	1.0	96
20	76	1.0	95	78	0.5	98
21	76	1.5	93	79	1.0	96
22	78	1.0	96	78	0.0	100
23	78	0.5	98	80	3.5	85
24	79	1.5	94	78	2.5	89
25	78	1.5	93	78	1.5	93
26	76	0.5	98	82	2.5	90
27	79	1.0	96	78	1.0	96
28	80	1.5	94	78	2.0	91
29	80	1.5	94	78	2.0	91
30	84	2.5	90	80	1.5	94
31	..	...	..	79	2.0	91

TEMPERATURE AND RELATIVE HUMIDITY AT BRITO AND TOLA STATIONS, 1898.

Day.	November.					December.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	83.0	70.0	76.5	2.0	91	81.5	75.9	78.1	3.1	87
2	81.0	74.5	77.5	2.5	89	84.0	77.5	80.8	2.8	88
3	83.0	70.0	77.0	3.5	85	84.7	78.0	81.0	2.6	90
4	83.0	70.0	77.5	2.0	91	84.9	76.0	79.4	2.9	87
5	84.0	75.0	80.0	3.0	87	83.2	78.3	80.5	5.4	77
6	85.5	74.5	80.0	2.5	89	81.0	76.1	78.9	3.9	83
7	84.0	76.5	80.0	3.0	87	83.0	76.8	79.8	4.9	79
8	84.0	76.0	79.0	2.5	89	82.8	75.8	78.1	3.9	
9	81.5	75.5	78.0	1.0	96	82.3	76.2	78.3	2.6	89
10	83.0	75.5	79.0	1.5	94	81.0	76.0	79.0	5.3	77
11	83.8	75.5	79.0	0.5	98	82.5	75.0	79.1	4.5	81
12	82.0	75.5	78.0	1.0	96	82.9	75.3	79.6	4.7	81
13	78.5	74.0	76.5	2.0	91	82.2	75.4	79.1	5.6	77
14	82.5	76.0	79.0	3.0	87	78.7	75.2	77.4	3.7	85
15	79.5	75.0	77.5	2.0	91	82.3	78.6	80.3	6.2	75
16	82.5	75.5	77.0	2.0	91	80.2	75.3	77.2	3.5	85
17	80.0	76.0	77.5	2.5	89	79.0	76.0	78.0	4.6	81
18	82.5	75.0	79.0	2.5	89	82.8	75.1	79.2	4.7	81
19	81.0	75.5	77.5	2.5	89	82.0	74.5	77.8	3.7	85
20	77.0	76.0	76.0	1.5	93	81.4	69.1	76.8	3.3	85
21	82.0	75.0	78.5	3.5	85	81.7	74.9	78.6	4.3	81
22	82.5	76.0	78.5	2.5	89	88.0	69.7	78.3	4.9	79
23	82.5	74.5	79.0	3.0	87	88.0	79.2	82.4	7.3	70
24	82.3	73.5	78.5	3.5	85	81.8	74.9	78.4	5.2	79
25	84.0	75.0	79.5	3.5	85	81.0	74.0	78.0	4.4	81
26	82.0	76.0	78.0	2.5	89	83.0	73.8	77.9	4.3	81
27	81.0	75.5	77.5	2.0	91	79.8	74.5	76.9	2.6	89
28	81.0	75.0	77.0	2.0	91	78.5	71.0	74.8	1.2	95
29	84.0	76.0	80.0	4.0	83	79.6	74.5	77.5	2.2	91
30	82.5	76.0	79.5	4.0	83	82.2	78.4	79.8	4.2	83
31	....	....	....	....	....	83.0	76.7	79.2	3.6	85

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION.

Month.	Temperature.			Mean. relative humidity.	Month.	Temperature.			Mean relative humidity.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
1898.					September	85	73	79.4	90.4
February	80	75	77.7	81.1	October.....	..	..	..	..
March	84	75	79.5	79.3	November	86	73	79.3	89.7
April	86	77	80.8	79.1	December.....	83	73	78.3	91.1
May	91	73	82.1	83.0	1899.				
June	91	73	81.4	84.8	January	82	75	78.5	85.1
July.....	85	74	79.7	86.6	February.	84	70	78.9	85.1
August	85	74	80.7	87.0	March	86	75	80.6	83.0

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1898.

Readings 7 A. M., 1 P. M. and 6 P. M.

Day.	February.					March.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1.....	....	....	....	....	....	79	78	78	4.5	81
2.....	....	....	....	....	....	80	75	78	3.0	87
3.....	....	....	....	....	....	82	76	79	3.5	85
4.....	....	....	....	....	....	84	79	81	4.5	81
5.....	....	....	....	....	....	83	79	80	4.5	81
6.....	....	....	....	....	....	81	78	80	5.0	79
7.....	....	....	....	....	....	80	77	79	4.5	81
8.....	....	....	....	....	....	81	76	79	4.5	81
9.....	....	....	....	....	....	81	76	79	5.0	79
10.....	....	....	....	....	....	80	76	78	4.5	81
11.....	....	....	....	....	....	82	77	80	4.5	81
12.....	....	....	....	....	....	83	77	80	4.5	81
13.....	....	....	....	....	....	78	77	78	4.0	83
14.....	....	....	....	....	....	84	78	81	5.0	80
15	80	76	78	4.5	81	83	77	80	5.5	77
16.....	78	76	77	4.0	83	82	78	80	5.5	77
17.....	80	76	78	4.0	83	83	77	80	6.0	75
18.....	79	75	78	4.0	83	81	77	79	5.5	77
19.....	79	76	78	3.5	85	81	76	79	5.5	77
20.....	80	76	78	4.0	83	82	76	80	5.5	77
21.....	78	76	77	4.5	80	82	77	80	5.5	77
22.....	77	76	77	4.5	80	82	78	80	6.0	75
23.....	80	75	78	4.5	81	81	77	79	5.0	79
24.....	80	77	79	5.0	79	80	78	79	3.0	87
25.....	....	....	....	....	....	82	78	79	4.0	83
26.....	79	75	78	5.5	77	83	77	80	6.5	74
27.....	80	75	77	4.0	83	79	78	78	4.5	81
28.....	78	76	77	5.5	76	83	77	80	5.5	77
29.....	....	....	....	....	.	82	77	80	6.0	75
30.....	....	....	....	....	.	82	76	80	6.5	74
31.....	....	....	....	....	....	83	77	80	5.5	74

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1898.

Day.	April.					May.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	83	77	80	5.5	77	85	81	83	5.5	78
2.....	83	77	81	6.0	76	85	81	83	5.0	80
3.....	84	77	80	5.5	77	86	80	83	5.5	78
4.....	84	78	80	4.5	81	87	79	83	5.5	78
5.....	79	79	79	3.5	85	87	81	83	5.5	78
6.....	84	79	81	3.5	86	88	79	84	5.0	80
7.....	80	80	80	5.0	79	88	82	85	5.5	78
8.....	85	77	80	5.5	77	88	82	85	5.5	78
9.....	83	77	81	6.5	74	87	82	84	6.0	77
10.....	81	77	79	4.5	81	89	81	84	6.0	77
11.....	83	78	80	5.0	79	84	80	82	4.0	84
12.....	81	77	79	4.0	83	91	81	86	5.5	79
13.....	84	81	82	5.5	78	88	82	84	6.0	77
14.....	83	78	81	5.0	80	88	79	83	5.5	78
15.....	84	79	81	6.0	76	82	81	*81	4.0	84
16.....	83	79	81	5.5	78	84	81	82	4.5	82
17.....	80	79	80	4.5	81	87	79	84	5.5	78
18.....	84	79	81	5.0	80	83	78	81	3.0	88
19.....	83	79	81	5.5	78	81	80	80	3.0	87
20.....	84	80	82	5.5	78	80	77	81	2.5	90
21.....	84	80	82	6.5	74	80	78	*79	2.0	91
22.....	84	79	81	5.0	80	76	73	*74	0.5	98
23.....	83	79	81	4.0	84	76	75	75	0.5	98
24.....	85	80	83	5.0	80	82	75	78	2.0	91
25.....	86	79	83	6.5	75	82	75	78	2.0	91
26.....	85	78	81	5.5	78	85	77	80	4.0	83
27.....	85	80	82	5.0	80	89	80	84	4.0	84
28.....	83	79	81	5.5	78	86	81	85	4.0	84
29.....	84	80	82	5.0	80	88	80	83	3.5	86
30.....	82	78	80	5.0	79	88	82	84	5.0	80
31.....	....	....	....	....	....	84	83	*83	5.5	78

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1898.

Day.	June.					July.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	87	83	84	5.5	78	80	80	*80	3.5	85
2.....	87	81	*84	5.5	78	82	75	78	3.0	87
3.....	87	83	85	6.5	75	81	78	79	2.5	89
4.....	87	80	83	5.5	78	80	79	80	3.5	85
5.....	88	83	85	6.0	77	83	79	80	4.0	83
6.....	91	83	87	6.0	77	84	80	81	4.5	82
7.....	82	78	81	3.0	88	83	79	81	3.0	88
8.....	..	..	..	...	..	83	80	81	4.5	82
9.....	91	81	*86	4.5	82	79	79	*79	3.5	85
10.....	88	81	84	4.0	84	81	75	78	1.5	93
11.....	85	81	84	5.0	80	83	76	80	2.5	89
12.....	83	79	*80	2.5	90	85	79	82	3.5	86
13.....	84	80	82	4.5	82	84	78	81	3.0	88
14.....	82	78	80	5.5	77	84	80	82	3.0	88
15.....	84	80	82	5.0	80	84	80	82	4.5	82

*Only two readings.

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1898.—Continued.

Day.	JUNE.					JULY.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
16.....	84	80	83	4.5	82	84	80	81	3.5	86
17.....	81	78	79	1.0	96	82	79	80	2.0	92
18.....	84	76	80	1.5	94	84	80	81	4.0	84
19.....	85	76	81	2.0	92	80	79	80	4.0	83
20.....	85	77	81	3.0	88	79	77	78	3.5	85
21.....	83	75	79	2.0	91	81	76	78	3.0	87
22.....	81	75	77	1.0	95	80	78	79	3.0	87
23.....	85	81	82	4.0	84	..	..	..	...	..
24.....	84	79	81	4.5	82	81	81	*81	3.5	86
25.....	84	80	80	5.0	79	80	79	80	3.0	87
26.....	84	76	80	3.0	87	78	77	78	2.0	91
27.....	81	74	77	1.0	95	80	74	77	4.0	83
28.....	76	73	75	0.5	98	79	78	78	3.5	85
29.....	82	78	77	4.0	83	82	80	80	1.5	94
30.....	82	79	81	3.5	86	78	74	76	3.0	87
31.....	..	..	..	...	..	83	78	81	3.0	88

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1898.

Day.	AUGUST.					SEPTEMBER.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	83	79	80	3.0	87	84	81	82	4.0	84
2.....	81	78	79	3.5	85	82	80	81	4.0	84
3.....	82	79	80	3.0	87	84	80	81	4.0	84
4.....	81	78	80	3.0	87	82	76	80	2.5	89
5.....	84	79	81	3.0	88	....	....	....	....	....
6.....	82	76	80	2.5	89	84	82	*83	4.0	84
7.....	82	80	81	3.5	86	85	81	82	4.0	84
8.....	83	80	82	4.0	84	84	79	81	4.0	84
9.....	84	79	81	3.5	86	81	78	80	3.0	87
10.....	82	80	81	4.0	84	80	73	77	1.5	93
11.....	85	79	82	3.5	86	82	76	78	2.0	91
12.....	81	79	80	4.0	83	82	77	80	2.5	89
13.....	83	75	79	2.5	89	77	74	76	0.5	98
14.....	79	76	78	2.0	91	78	74	76	0.5	98
15.....	83	76	80	2.5	89	83	78	80	2.0	90
16.....	83	80	81	3.0	88	82	76	79	3.0	87
17.....	83	79	81	3.0	88	85	76	81	3.5	86
18.....	83	79	82	4.0	84	84	81	83	4.0	84
19.....	84	76	81	3.5	86	....	....	....	....	....
20.....	84	80	82	3.5	86	79	74	*76	2.0	91
21.....	80	74	78	2.0	91	80	73	77	1.5	93
22.....	84	80	82	4.5	82	80	76	78	1.5	93
23.....	85	81	83	4.0	84	80	77	78	1.0	96
24.....	84	80	82	4.0	84	84	77	80	2.0	92
25.....	84	81	82	3.0	88	83	76	80	2.0	92
26.....	85	77	82	3.0	88	78	76	77	1.0	95
27.....	83	78	80	2.5	89	80	76	77	0.5	98
28.....	84	75	80	3.0	87	80	76	78	1.5	93
29.....	82	76	80	2.0	92	85	75	80	2.0	92
30.....	84	75	80	3.0	87	85	78	81	2.5	90
31.....	81	80	81	2.5	90	....	....	....	....	...

* Only two readings.

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1898.

Day.	October.					November.				
	Max.	Min.	Mean.	Mean t−t′	Relative humidity.	Max.	Min.	Mean.	Mean t−t.′	Relative humidity.
1.....	....	....	....	....	....	86.0	77.0	80.5	4.5	81.5
2.....	....	....	....	....	....	83.5	75.0	78.5	3.5	85.0
3.....	....	....	....	....	....	83.5	74.5	78.5	3.0	87.0
4.....	....	....	....	....	...	81.1	78.2	80.0	3.0	87.0
5.....	....	....	....	....	...	82.5	78.5	80.5	3.5	85.5
6.....	....	....	....	....	....	82.0	80.0	81.0	3.5	86.0
7.....	....	....	....	....	....	82.5	80.0	81.5	5.0	80.0
8.....	....	....	....	....	....	82.0	79.0	80.5	3.0	87.5
9.....	....	....	....	....	....	79.0	77.0	78.0	1.0	96.0
10.....	....	....	....	....	....	82.0	79.2	80.0	1.5	94.0
11.....	....	....	....	....	....	82.5	78.0	80.0	0.5	98.0
12.....	....	....	....	....	....	82.1	77.0	79.5	1.0	96.0
13.....	....	....	....	....	....	79.2	77.5	78.5	0.5	98.0
14.....	....	....	....	....	....	80.1	78.1	79.5	1.5	94.0
15.....	....	....	....	....	....	81.5	78.8	80.0	2.0	92.0
16.....	....	....	....	....	....	81.2	77.0	79.0	2.5	89.0
17.....	....	....	....	....	....	80.0	77.5	79.0	0.5	79.0
18.....	....	....	....	....	....	80.3	73.2	78.0	1.0	96.0
19.....	....	....	....	....	....	80.7	77.5	79.0	3.0	87.0
20.....	....	....	....	....	....	80.0	76.5	78.0	1.5	93.0
21.....	....	....	....	....	....	79.2	76.9	78.5	2.0	91.0
22.....	....	....	....	....	....	81.0	78.8	79.5	2.5	89.8
23.....	....	....	....	....	....	81.0	77.6	80.0	2.0	92.0
24.....	....	....	....	....	....	81.0	77.0	79.5	3.0	87.0
25.....	....	....	....	....	....	81.0	77.0	79.5	1.3	94.0
26.....	....	77.8	....	....	....	81.2	77.0	79.5	1.5	94.0
27.....	83.0	78.0	80.5	3.5	85.5	80.6	75.1	78.0	2.5	89.0
28.....	81.0	74.0	77.5	1.5	93.0	78.0	75.2	76.5	2.5	89.0
29.....	84.5	77.0	80.0	3.0	87.0	80.5	78.3	79.5	3.0	87.0
30.....	83.0	77.0	79.0	2.0	91.0	81.5	77.4	79.0	3.0	87.0
31.....	85.0	79.0	82.0	3.0	88.0	....	.. .	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1898-9.

Day.	December, 1898.					January, 1899.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	....	77.0	77.4	3.20	87	....	....	....	....	....
2.....	81.2	78.6	80.2	2.06	92	....	....	....	....	....
3.....	83.0	78.9	80.8	2.43	90	....	....	....	....	....
4	82.8	79.1	81.2	3.53	86	78.5	77.0	77.8	2.0	91
5.....	82.6	77.8	78.5	4.10	83	79.5	76.5	78.0	3.0	87
6.....	80.1	76.3	77.4	2.76	89	79.0	77.0	77.5	3.5	85
7.....	....	77.4	....	....	....	80.0	77.0	78.5	4.0	83
8.....	80.5	79.0	78.6	3.85	83	80.5	76.0	78.5	4.5	81
9.....	79.2	77.6	79.8	2.26	92	80.5	76.0	78.5	3.5	85
10.....	80.5	79.3	79.2	4.63	81	80.0	75.5	77.0	3.0	87
11.....	82.0	76.5	78.8	3.23	87	80.5	77.0	78.5	3.0	87
12.....	....	78.2	....	....	....	81.0	76.5	78.0	4.0	83
13.....	80.2	76.8	78.0	2.90	87	81.0	77.0	79.0	3.0	87
14.....	79.2	76.8	78.9	3.50	85	....	....	....	....	....
15.....	80.3	75.2	76.9	3.53	85	81.5	78.0	80.0	4.5	81

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1898-9.—Continued.

Day.	December, 1898.					January, 1899.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
16	77.4	76.4	76.1	2.96	87	79.5	76.5	78.0	2.5	89
17.....	....	75.0	....	....	....	81.0	76.0	78.5	3.0	87
18.....	....	76.2	....	....	....	80.5	76.0	78.5	3.0	87
19.....	79.8	76.4	78.3	3.40	85	80.5	76.0	79.0	5.0	79
20.....	81.4	76.4	78.6	2.53	89	79.5	75.5	77.5	4.0	83
21.....	79.2	76.3	77.6	2.90	87	79.5	75.5	77.5	3.0	87
22.....	79.7	74.7	77.2	1.50	93	79.0	75.0	77.5	3.5	85
23.....	80.0	76.4	78.7	2.36	89	80.5	75.0	78.0	3.0	87
24.....	....	76.0	....	....	....	....	....	....	....	....
25.....	....	....	....	....	....	82.0	78.0	80.0	4.0	83
26.....	....	....	....	....	....	81.0	78.0	79.5	3.5	85
27.....	....	....	....	....	....	80.0	76.5	79.0	4.0	83
28.....	75.1	73.5	74.2	1.00	95	81.0	76.0	78.0	3.0	87
29.....	80.0	76.0	78.3	3.96	83	79.5	77.0	78.5	3.5	85
30.....	79.9	76.2	77.6	2.20	91	80.5	76.0	79.0	4.0	83
31.....	79.5	76.9	78.5	2.63	89	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT LAS LAJAS STATION, 1899.

Day.	February.					March.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t-t′.	Relative humidity.
1.....	80.5	76.5	78.5	3.0	87	81.5	76.0	79.0	3.5	85
2.....	....	....	....	....	....	82.5	75.0	79.5	3.5	85
3.....	81.0	76.0	79.0	3.5	85	82.0	76.0	79.5	3.5	85
4.....	81.0	76.5	79.0	3.5	85	82.0	75.0	79.0	3.0	87
5.....	80.5	76.5	78.5	4.0	83	83.0	77.0	80.5	4.0	83
6.....	82.0	76.0	78.5	3.0	87	83.0	77.0	79.0	4.0	83
7.....	....	....	....	....	....	....	....	....	....	....
8.	83.0	....	....	....	....	....	....	....	....	....
9.....	81.0	77.0	79.5	5.0	79	81.5	77.0	79.5	3.5	85
10.....	....	....	....	....	....	80.5	78.0	79.5	3.5	55
11.....	....	....	....	....	....	82.0	76.0	79.5	4.0	83
12.....	80.0	....	....	....	....	83.0	76.0	79.0	3.5	85
13.....	80.0	77.0	78.5	5.5	77	82.5	77.0	79.0	3.5	85
14.....	75.3	70.0	74.0	4.0	83	80.5	78.5	80.0	3.0	87
15.....	....	....	....	....	....	84.0	76.0	80.5	3.5	86
16.....	80.0	75.0	78.5	2.0	91	86.0	79.0	82.5	3.5	86
17.....	76.5	75.5	76.0	2.0	91	84.5	79.0	81.0	4.5	82
18.....	82.0	76.0	79.0	3.0	87	82.5	....	....	....	....
19.....	81.5	76.0	78.5	4.0	83	....	....	....	....	....
20.....	84.0	77.0	80.5	4.0	84	84.0	78.0	81.5	4.5	82
21.....	84.0	76.0	80.0	3.0	87	84.0	78.0	81.5	5.5	78
22.....	82 5	77.0	80.0	4.0	83	84.5	78.5	81.5	5.0	80
23.....	83.5	77.0	80.5	4.0	84	84.0	79.0	81.5	5.0	80
24.....	....	....	....	....	....	82.5	78.5	80.5	4.5	81
25.....	85.0	....	....	....	....	84.0	....	....	....	....
26.....	84.0	76.5	81.0	2.0	92	85.0	80.0	82.5	5.5	78
27.....	83.0	78.0	80.5	3.0	88	82.5	78.5	81.0	5.0	80
28.....	81.5	74.0	78.5	4.0	83	84.5	78.5	82.5	5.5	78
29.....	....	....	....	....	....	85.0	78.0	82.5	5.0	80
30.....	....	....	....	....	....	....	....	....	....	....
31.....	....	....	....	....	....	82.5	80.0	81.5	3.5	86

TEMPERATURE AND RELATIVE HUMIDITY AT RIO VIEJO STATION, 1898.

Month.	Temperature.			Mean relative humidity.
	Maximum.	Minimum.	Mean.	
February	89	63	78.1	58.9
March	97	62	78.8	59.1
April	94	69	82.8	59.4
May	96	71	82.3	71.0
June	94	70	80.6	81.4
July	89	70	78.8	79.6
August	90	71	78.4	83.1
September	89	70	78.0	86.2

TEMPERATURE AND RELATIVE HUMIDITY AT RIO VIEJO STATION, 1898.

Day.	February.					March.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	....	....	....	....	....	91	68	79	11 0	57
2	....	....	....	....	....	93	67	81	9.5	63
3	....	....	....	....	....	97	66	78	6.6	73
4	....	....	....	....	....	86	69	79	9.0	64
5	....	....	....	....	....	85	72	78	9.0	63
6	....	....	....	....	....	83	69	76	8.0	66
7	84	72	77.7	10	60	87	71	79	12.0	53
8	85	66	75.7	11	56	87	69	79	11.0	57
9	89	68	78.3	10	61	87	70	79	11.5	55
10	88	70	78.3	7	71	92	70	81	11.5	56
11	87	72	79.3	12	53	94	69	81	11.0	58
12	89	71	79.7	10	61	....	62	....	....	....
13	82	73	78.0	9	63	....	....	....	....	....
14	87	71	79.0	12	53	88	72	81	11.5	56
15	85	72	77.7	10	60	89	66	79	10.5	58
16	....	66	....	....	....	85	68	78	9.5	62
17	....	....	....	....	....	87	70	79	11.5	55
18	86	63	76.0	10.5	57	88	72	80	10.5	59
19	86	70	79.0	10	60	83	68	75	7.5	68
20	87	70	78.7	10.5	58	83	70	77	9.5	61
21	89	66	78.3	10	60	89	69	79	11.0	57
22	88	70	78 7	10	60	87	70	80	10.5	59
23	85	68	77.3	9.5	61	84	70	77	8.5	65
24	85	68	77.0	9.5	61	91	69	78	10.0	60
25	83	71	77.0	10.5	57	87	72	78	9.5	62
26	....	66	....	....	....	87	71	79	12.5	52
27	....	....	....	....	....	86	71	79	12.0	53
28	89	69	79.3	13.5	48	88	72	79	11.0	57
29	....	....	....	....	....	87	72	80	12.5	52
30	....	....	....	....	....	87	73	80	13.0	51
31	....	....	....	....	....	88	70	79	9.5	62

TEMPERATURE AND RELATIVE HUMIDITY AT RIO VIEJO STATION, 1898.

Day.	April.					May.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	87	69	79	9.5	62	90	79	83	8.5	68
2	....	....	....	....	....	88	77	82	9.5	64
3	....	....	....	....	....	83	78	81	9.5	64
4	....	....	....	....	....	92	80	85	13.0	53
5	90	74	82	10.0	62	91	77	82	10.0	62
6	89	75	82	9.5	63	96	80	86	12.0	57
7	88	75	82	11.5	57	90	82	85	10.5	62
8	89	71	79	10.5	58	93	81	86	12.0	57
9	....	....	....	....	....	92	81	85	11.5	58
10	....	....	....	....	....	91	78	85	11.0	60
11	89	72	81	11.0	58	95	84	89	12.5	57
12	90	78	82	9.5	63	94	80	86	11.5	58
13	88	69	80	9.5	62	93	79	85	12.5	55
14	93	72	85	12.0	56	95	80	87	14.5	50
15	94	72	84	11.5	58	96	79	86	9.5	65
16	86	76	82	8.5	67	90	79	83	8.5	68
17	93	78	85	9.5	64	90	81	84	9.0	66
18	90	79	84	9.5	64	90	77	82	6.5	74
19	90	75	83	9.0	66	82	73	78	2.5	89
20	82	79	81	8.0	68	86	74	80	3.5	85
21	92	80	84	12.0	56	85	74	80	3.5	85
22	89	70	80	11.0	57	74	71	72	1.0	95
23	91	79	84	13.0	53	77	72	74	1.5	93
24	91	74	82	11.5	56	74	72	73	1.0	95
25	90	84	87	15.5	46	83	74	78	2.5	89
26	92	83	87	13.0	54	84	78	81	4.5	82
27	91	81	85	12.5	54	91	78	84	5.5	78
28	93	76	83	10.5	60	93	75	83	5.0	80
29	90	81	84	12.0	56	92	79	84	5.5	78
30	89	74	82	9.5	64	90	76	81	5.5	78
31	....	....	....	....	....	91	76	82	6.5	74

TEMPERATURE AND RELATIVE HUMIDITY AT RIO VIEJO STATION, 1898.

Day.	June.					July.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	89	82	85	9.5	64	85	75	79	3.0	87
2	92	80	85	6.5	75	83	77	80	4.5	81
3	92	81	85	7.5	72	84	76	79	5.5	77
4	92	79	85	7.0	73	80	75	78	5.5	77
5	91	78	84	6.5	75	86	78	81	7.5	70
6	90	72	81	4.5	82	86	74	78	4.5	81
7	94	74	84	5.0	80	85	70	77	4.5	80
8	92	80	84	5.5	78	85	76	79	6.0	75
9	91	80	84	6.5	75	....	....	....	....	....
10	92	77	82	4.5	82	....	....	....	....	....
11	87	78	82	4.0	84	....	....	....	....	....
12	85	75	79	4.0	83	85	77	80	3.5	85
13	85	75	80	5.5	77	89	75	81	4.5	82
14	88	73	78	7.5	69	82	75	78	2.5	89
15	88	75	81	6.5	74	89	76	81	5.0	80

TEMPERATURE AND RELATIVE HUMIDITY AT RIO VIEJO STATION, 1898.—Continued.

Day.	JUNE.					JULY.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
16	92	75	82	5.5	78	87	77	81	5.5	78
17	93	78	85	5.0	80	88	78	82	6.0	76
18	80	74	77	2.5	89	80	79	80	5.5	74
19	86	73	78	1.5	93	86	77	80	6.5	74
20	85	74	78	2.0	91	80	73	76	3.0	87
21	90	73	79	2.0	91	83	74	77	4.5	80
22	89	71	79	2.5	89	87	72	80	5.0	79
23	85	75	80	3.0	87	82	73	77	5.5	76
24	80	72	76	2.0	91	87	77	81	6.5	74
25	84	72	78	3.5	85	87	77	80	6.5	74
26	84	78	80	5.0	79	86	71	77	4.0	83
27	87	71	77	2.0	91	87	71	78	6.0	75
28	77	70	74	2.0	91	78	70	73	2.5	88
29	83	73	78	3.5	85	86	73	78	4.5	81
30	84	73	78	5.5	77	79	70	75	2.5	89
31	....	....	....	....	....	87	75	81	5.5	78

TEMPERATURE AND RELATIVE HUMIDITY AT RIO VIEJO STATION, 1898.

Day.	AUGUST.					SEPTEMBER.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1	80	75	77	3.5	85	85	77	80	5.5	77
2	86	76	80	5.5	77	84	76	80	3.5	85
3	84	72	78	4.0	83	82	78	79	4.0	83
4	80	72	75	3.5	85	82	78	79	4.5	81
5	83	73	76	....	....	78	76	77	3.0	87
6	....	....	....	....	....	78	74	77	0.0	....
7	....	....	....	....	....	80	73	76	2.5	89
8	....	....	....	....	....	80	75	78	3.5	85
9	....	....	....	....	....	....	....	....	....	....
10	....	....	....	....	....	....	....	....	....	....
11	85	71	78	3.5	85	....	....	....	....	....
12	....	....	....	....	....	....	....	....	....	....
13	....	....	....	....	....	....	....	....	....	....
14	83	73	79	4.0	83	86	73	79	3.5	85
15	88	75	79	2.5	89	83	71	76	2.0	91
16	....	....	....	....	.....	86	70	78	4.0	83
17	....	....	....	....	....	84	76	80	5.5	77
18	....	....	....	...	....	86	74	79	5.5	77
19	....	...	....	....	....	88	71	78	3.5	85
20	....	....	....	....	....	74	71	73	0.5	98
21	....	....	....	....	....	83	73	77	1.5	93
22	....	....	....	....	....	87	73	78	2.0	91
23	....	....	....	....	....	84	73	78	2.5	89
24	85	78	80	5.5	77	89	75	80	3.5	85
25	80	77	79	4.5	81	89	74	80	3.0	87
26	86	75	79	4.0	83	85	74	78	2.5	89
27	90	72	80	2.5	89	80	74	77	2.0	91
28	79	71	75	2.5	89	83	73	77	2.5	89
29	85	72	78	4.0	83	....	....	....	....	....
30	87	77	81	4.5	81	....	....	....	....	....
31	86	77	80	5.5	77	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION.

Month.	Temperature.			Mean relative humidity.	Month.	Temperature.			Mean relative humidity.
	Max.	Min.	Mean.			Max.	Min.	Mean.	
1898.					October....	90.	74.	79.8	88.8
March.....	88.	70.	78.1	75.8	November..	88.5	72.	77.9	90.1
April	88.5	70.5	78.5	79.1	December..	88.	70.	76.5	88.8
May	91.	73.	80.0	85.9	1899.				
June.....	90.	73.	79.5	88.9	January ...	84.	69.	75.9	90.5
July	89.5	72.	78.2	88.9	February...	85.	66.	76.9	87.5
August	89.	73.5	79.1	89.5	March.....	90.	70.	77.6	83.7
September .	90.	72.5	79.6	87.3					

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1898.

Day.	March.										
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Day.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
9....	82.5	70.5	75.5	3.5	85	20....	86.5	71.0	78.5	8.0	67.5
10....	83.0	72.0	77.5	4.5	80.5	21....	84.0	72.0	78.0	6.5	73
11....	85.0	72.5	78.5	6.0	75	22....	83.0	72.0	78.5	8.0	67.5
12....	84.5	72.5	78.0	5.0	79	23....	81.0	71.5	76.5	5.0	78
13....	88.0	71.0	78.5	5.0	79	24....	83.0	71.0	77.5	3.5	85
14....	87.0	74.0	79.5	6.5	73	25....	82.0	73.0	77.0	3.0	87
15....	86.5	72.5	80.0	6.5	73	26....	85.0	71.0	77.5	5.0	78.5
16....	87.0	71.0	78.5	6.5	73	27....	84.0	72.0	77.5	4.0	83
17....	86.0	73.0	78.5	7.0	71	28....	86.0	70.0	78.0	6.5	73
18....	82.0	73.0	77.5	5.5	76.5	29....	85.0	72.0	79.5	7.5	70
19....	87.0	75.0	80.0	9.0	64						

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1898.

Day.	April.					May.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1.....	83.0	72.0	77.0	4.0	83	82.0	75.0	78.0	2.5	89
2.....	88.0	73.5	80.0	7.0	72	82.5	74.5	77.5	2.5	89
3.....	86.0	72.0	77.5	6.5	73	87.0	77.0	81.0	4.0	84
4.....	85.0	73.0	78.0	4.5	81	89.0	76.0	80.0	4.0	83
5.....	77.0	75.0	75.5	1.5	93	86.0	74.0	79.5	5.0	79
6.....	83.5	75.5	77.0	2.0	91	89.0	75.5	80.5	4.0	83.5
7.....	82.5	76.0	78.0	4.5	81	88.5	77.0	81.5	4.0	84
8.....	86.0	74.5	79.0	7.5	70	91.0	78.5	83.5	4.5	82
9.....	86.0	72.0	78.0	6.5	73	....	79.5	....	....	....
10.....	86.5	75.0	79.0	5.5	77	85.5	78.0	80.5	3.0	87.5
11.....	87.0	74.0	77.5	3.0	87	77.0	75.0	76.0	1.5	93
12.....	85.0	75.0	79.0	5.0	79	87.5	75.5	81.0	4.5	82
13.....	87.0	74.0	80.0	6.0	75	84.0	78.5	80.5	4.0	83.5
14.....	85.5	72.5	78.5	5.0	79	89.0	75.5	82.0	5.0	80
15.....	87.0	74.5	80.0	8.0	68	87.5	77.0	80.5	4.0	83.5
16.....	88.5	70.5	79.0	7.0	71	82.5	74.5	78.0	3.0	87
17.....	80.0	73.0	76.5	2.5	89	....	75.0	....	....	....
18.....	86.0	73.5	79.0	6.0	75	87.0	74.5	79.0	3.0	87
19.....	88.0	75.0	80.5	5.5	77.5	84.5	76.0	79.0	3.0	87
20.....	87.0	75.0	80.5	6.5	74	....	74.0	....	....	....
21.....	88.0	74.5	81.0	7.5	70	86.0	76.5	79.5	2.5	89
22.....	82.0	74.0	78.0	4.5	81	79.5	76.0	77.0	1.5	93
23.....	80.0	74.0	75.5	2.0	91	79.0	73.0	76.0	1.5	93
24.....	87.0	76.5	81.0	6.0	75	85.0	75.0	79.0	3.0	87
25.....	88.0	75.0	81.0	4.0	84	86.0	77.0	81.5	3.5	86
26.....	84.5	73.0	77.0	3.0	87	88.0	80.0	83.0	5.0	80
27.....	86.5	72.0	77.0	3.0	87	90.0	81.0	85.0	5.0	80
28.....	85.0	71.0	78.0	5.0	79	90.0	76.5	83.0	4.0	84
29.....	88.0	74.0	80.0	6.0	75	89.5	77.0	78.0	1.5	93
30.....	86.5	72.5	79.0	5.5	77	86.0	76.0	80.5	2.5	89.5
31.....	....	....	....	....	....	85.0	78.5	80.0	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1898.

Day.	JUNE.					JULY.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	83.0	74.5	78.5	3.0	87	83.0	76.0	78.5	2.5	89
2.....	87.5	73.0	81.0	4.5	82	83.0	73.5	77.5	2.0	91
3.....	88.0	75.0	81.0	4.5	82	83.0	73.0	78.0	2.5	89
4.....	86.5	77.5	81.0	4.0	84	82.0	76.5	78.5	3.0	87
5.....	88.5	77.0	82.0	4.0	84	81.0	76.0	78.0	2.5	89
6.....	90.0	79.0	84.0	4.5	82	87.0	76.0	80.0	3.0	87
7.....	83.5	76.5	80.5	3.0	87.5	82.0	75.0	78.0	2.0	91
8.....	89.5	78.0	83.5	5.0	80	83.0	75.5	78.5	3.0	87
9.....	89.0	78.0	82.5	4.0	84	83.5	74.5	78.0	3.5	85
10.....	87.0	77.0	81.5	2.5	90	83.0	76.0	78.5	3.5	85
11.....	80.0	76.0	78.5	1.5	93.5	87.5	74.5	79.6	3.5	85
12.....	84.0	74.5	79.5	2.0	91.5	86.0	76.5	80.0	3.5	85
13.....	79.5	76.0	77.5	1.0	95.5	88.0	76.0	81.5	3.0	88
14.....	79.5	73.0	76.0	3.0	87	86.5	73.5	79.5	2.5	89
15.....	85.0	73.0	79.0	1.5	94	89.5	76.5	82.0	3.5	86
16.....	85.0	76.0	80.0	1.5	94	87.0	79.0	81.5	3.5	86
17.....	86.0	77.5	82.0	2.5	90	82.0	76.5	79.5	2.5	89
18.....	88.0	77.0	81.5	2.0	92	82.0	73.0	77.0	2.0	91
19.....	87.0	74.0	79.5	2.0	91.5	82.5	75.0	78.0	2.5	89
20.....	87.0	77.0	81.0	2.0	92	79.5	73.0	75.5	1.5	93
21.....	86.0	75.0	78.5	2.5	89	75.0	74.5	74.5	1.0	95
22.....	84.5	74.0	79.0	3.0	87	79.5	73.5	76.0	1.5	93
23.....	82.5	75.5	77.5	2.0	91	82.0	74.0	77.5	2.5	89
24.....	81.0	74.5	78.0	2.2	91	83.0	75.0	78.5	2.5	89
25.....	82.0	75.0	78.0	2.0	91	81.0	75.0	77.5	2.5	89
26.....	83.0	74.5	77.5	2.5	89	79.0	74.0	76.0	1.5	93
27.....	78.0	73.0	75.0	0.7	98	84.0	72.0	77.5	3.0	87
28.....	81.5	73.5	77.5	2.0	91	82.5	73.5	78.0	2.0	91
29.....	84.0	74.0	79.0	2.0	91	79.5	74.0	77.5	2.0	91
30.....	84.0	74.5	79.0	3.0	87	81.0	73.0	77.0	2.0	91
31.....	....	....	....	....	....	85.0	74.0	79.0	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1898.

Day.	AUGUST.					SEPTEMBER.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	80.0	77.0	79.0	2.0	91	84.0	75.5	79.0	2.0	91
2.....	83.0	73.5	77.0	2.0	91	85.0	73.0	78.0	2.0	91
3.....	83.0	74.5	78.0	2.5	89	81.5	74.5	77.5	1.5	93
4.....	82.5	74.5	77.0	1.5	93	86.0	75.0	79.5	2.0	91.5
5	84.0	76.0	78.5	2.0	91	86.0	78.5	81.5	5.0	80
6.....	85.0	74.0	79.0	2.5	89	79.0	75.0	76.5	1.0	95
7.....	80.0	75.0	77.0	1.5	93	79.0	75.0	77.0	2.0	91
8.....	84.0	75.0	78.0	2.0	91	80.0	76.0	77.5	2.0	91
9.....	77.5	74.0	76.0	1.5	93	83.0	72.5	77.1	1.5	93
10.....	85.0	76.5	79.5	2.5	89	85.0	73.0	79.5	3.0	87
11.....	81.0	76.0	78.0	1.5	93	81.5	75.0	79.0	2.2	91
12.....	81.0	74.5	77.0	1.5	93	85.0	75.0	79.5	2.5	89
13.....	84 0	75.0	78.5	1.5	93.5	86.0	77.0	80.5	3.0	87.5
14.....	85.0	75.0	79.0	2.5	89	82.0	74.0	77.5	2.5	89
15.....	86.0	78.0	81.0	2.0	92	86.0	75.0	79.5	3.0	87

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1898.—Continued.

Day.	August.					September.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
16.....	88.0	78.0	81.5	3.5	86	85.0	74.0	79.5	2.5	89
17.....	87.0	78.5	81.5	3.0	88	87.0	74.5	81.0	3.0	88
18.....	88.5	77.0	81.5	3.5	86	88.0	77.0	82.0	5.5	78
19.....	89.0	74.0	79.5	3.5	85	83.0	76.0	78.5	2.5	89
20.....	84.0	74.5	78.5	3.0	87	85.0	74.0	78.0	2.5	89
21.....	84.0	76.0	79.5	2.5	89	85.5	74.0	79.0	4.0	83
22.....	88.5	73.5	79.5	3.0	87	87.0	74.0	79.0	3.0	87
23.....	....	75.5	....	1.0	....	84.0	73.5	79.5	3.0	87
24.....	84.0	75.0	78.5	2 5	89	88.0	76.0	82.0	3.5	86
25.....	87.5	76.0	80.5	3.0	87.5	88.5	78.0	83.0	4.5	82
26.....	85.0	76.5	79.5	2.0	91.5	90.0	75.0	80.5	3.6	85
27.....	86.0	76.0	80.5	2.5	89.5	88.0	75.0	80.5	4.0	83.5
28.....	86.0	78.0	80.5	3.5	85.5	87.5	76.5	80.5	3.0	87.5
29.....	83.0	74.5	79.0	2.5	89	88.0	80.0	84.0	4.5	82
30.....	87.0	79.0	81.5	3.5	86	90.0	78.0	84.0	5.5	78.5
31.....	87.0	75.0	79.5	2.5	89	....	...	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1898.

Day.	October.					November.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	90.0	79.0	82.5	4.1	84	86.0	79.0	82.5	4.0	84.0
2.....	89.0	78.0	83.0	4.5	82	88.0	81.0	83.5	6.0	76.5
3.....	88.0	79.0	82.5	3.5	86	88.0	77.0	81.5	4.0	84.0
4.....	87.0	75.0	79.5	3.0	87	82.0	75.0	77.5	2.0	91.0
5.....	82.0	75.0	78.0	2.0	91	82.5	75.0	78.5	2.0	91.0
6.....	87.0	74.0	79.5	3.0	87	81.5	76.0	78.0	2.0	91.0
7.....	87.5	76.0	82.0	3·5	86	85.0	75.0	79.5	3.0	87.0
8.....	78.5	76.0	77.0	1.5	93	88.5	75.0	80.5	4.0	83.5
9.....	83.5	76.0	79.5	2.0	91.5	82.0	76.0	78.0	1.5	93.0
10.....	86.0	75.0	80.5	3.5	85.5	83.0	76.0	79.0	2.5	89.0
11.....	88.0	74.0	80.5	2.5	89.5	85.0	76.0	79.5	2.5	89.0
12.....	88.0	77.0	81.5	3.0	88	82.0	75.0	78.0	1.5	93.0
13.....	82.0	75.0	78.5	2.0	91	77.0	74.0	75.5	1.0	95.0
14.....	84.0	74.5	78.0	1.5	93	80.0	74.0	76.5	1.5	93.0
15.....	84.0	76.0	79.0	2.0	91	81.0	74.5	77.0	1.5	93.0
16.....	85.0	74.0	78.5	2.0	91	74.5	73.0	74.0	1.5	93.0
17.....	86.0	75.0	79.0	2.0	91	78.0	73.5	75.5	1.5	93.0
18.....	85.0	75.0	78.5	2.0	91	79.0	74.0	75.5	1.5	93.0
19.....	84.0	75.0	80.0	3.0	87	82.0	72.0	79.5	3.0	87.0
20.....	86.0	76.0	80.5	2.5	89.5	78.0	73.0	75.5	1.5	93.0
21.....	86.5	77.0	81.0	3.0	88	82.0	74.0	77.5	2.5	89·0
22.....	87.0	77.0	80.5	3.0	87.5	82.0	74.0	77.5	2.5	89.0
23.....	84.0	76.0	79.0	2.5	89	83.5	75.0	78.5	3.0	87.0
24.....	82.5	75.0	78.0	2.0	91	85.0	75·0	78.5	2.0	91.0
25.....	77.0	75.0	76.0	1.5	93	78.0	74.0	76.0	1.5	93.0
26.....	82.5	75.0	78.0	2.0	91	81.0	74.5	77.0	1.0	95.0
27.....	83.5	74.0	78.0	2.0	91	79.0	74.0	76.5	1.0	95.0
28	85.0	74.0	80.0	2.5	89	81.0	75.0	77.5	1.5	93.0
29.....	86.0	78.5	82.0	4.0	84	83.0	76.0	78.5	2.0	91.0
30.....	88.0	79.0	83.0	3.5	86	80.0	74·0	76.5	2.5	89.0
31.....	87.0	77.0	81.5	2.5	90	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1898-99.

Day.	December, 1898.					January, 1899.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	76.5	73.0	75.0	0.9	95	82.0	72.0	76.5	3.5	85
2.....	87.0	74.0	79.8	2.3	89	82.0	73.0	76.5	3.0	87
3.....	83.0	76.0	79.0	2.4	89	83.0	72.0	76.5	3.0	87
4.....	84.5	75.0	79.1	2.8	87	80.0	72.0	75.5	1.5	93
5.....	82.0	75.0	77.3	3.0	87	80.0	74.0	76.5	2.0	91
6.....	80.0	74.0	77.0	2.0	91	80.0	73.0	75.5	2.0	91
7.....	82.5	74.0	77.5	3.2	87	83.0	73.0	76.5	3.0	87
8.....	79.0	73.0	75.6	2.3	89	82.0	73.0	76.0	2.5	89
9.....	84.0	73.0	77.0	3.0	87	79.0	73.0	75.5	1.5	93
10.....	78.5	73.0	75.5	1.2	95	79.0	72.0	75.5	2.0	91
11.....	81.5	73.0	77.1	2.8	87	79.0	71.0	75.0	1.5	93
12.....	81.0	71.0	76.3	3.0	87	78.0	73.0	75.5	1.0	95
13.....	81.0	72.0	76.6	2.6	89	79.0	75.0	76.5	1.0	95
14	83.0	72.0	76.3	3.7	85	80.0	74.0	76.0	1.5	93
15.....	82.0	70.5	76.1	2.6	89	81.0	75.0	77.5	1.5	93
16.....	76.0	72.0	73.6	1.3	93	78.0	73.0	75.5	1.0	95
17.....	78.0	71.5	74.1	1.5	93	80.0	71.0	75.5	1.5	93
18.....	81.0	72.0	76.0	2.7	89	82.0	73.0	76.0	2.5	89
19.....	82.0	70.0	74.6	1.6	93	82.0	73.0	77.0	3.5	85
20.....	82.0	72.0	77.0	2.0	91	77.0	72.0	74.0	1.5	93
21.....	84.0	71.5	76.5	2.9	87	77.0	72.0	74.5	1.5	93
22.....	82.0	73.0	76.0	2.7	89	78.0	71.0	74.0	2.0	91
23.....	84.0	72.0	74.0	0.4	98	82.0	72.0	76.5	2.5	89
24.....	84.0	73.0	77.0	4.0	83	84.0	72.0	77.5	2.5	89
25.....	84.0	72.0	77.0	3.0	87	83.0	74.0	78.0	2.5	89
26.....	81.0	74.0	76.6	4.0	82.5	78.0	72.0	75.5	2.0	91
27.....	80.0	71.0	76.6	2.6	89	83.0	71.0	77.0	2.0	91
28.....	77.0	72.0	74.6	2.6	88.5	82.0	69.0	75.0	2.0	91
29.....	80.0	72.0	75.6	2.0	91	80.0	72.0	75.0	2.5	89
30.....	80.0	73.0	76.3	2.3	89	84.0	72.0	76.5	3.5	85
31.....	88.0	75.0	81.0	5.7	78	81.0	69.0	75.0	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1899.

Day.	February.					March.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	80	73	76.5	2.5	89	75	72	73.0	1.5	93
2.....	83	71	76.5	3.0	87	80	71	75.5	2·5	89
3.....	82	72	76.5	4.0	82	75	73	74.0	2.5	89
4.....	78	72	75.0	2.5	89	78	74	76.5	2.5	89
5.....	83	72	77.0	3.5	85	84	76	79.5	5.5	77
6.....	82	72	76.5	2.5	89	83	74	77.0	3.5	85
7.....	83	72	77.5	3.5	85	80	74	76.0	3.5	85
8.....	85	75	80.0	3.5	85	76	72	73.5	2.5	89
9.....	80	74	77.5	2.5	89	82	71	74.5	3.5	85
10.....	85	72	78.5	4.0	83	83	70	75.0	4.0	82
11.....	85	74	78.5	3.5	85	82	70	75.0	3.5	85
12.....	78	73	75.5	1.0	95	83	72	77.0	3.5	85
13.....	80	72	75.0	2.0	91	80	72	76.0	2.5	89
14.....	75	66	70.5	3.5	83	83	74	78.0	3.5	85
15..	79	69	74.0	....	....	79	72	76.5	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT FORT SAN CARLOS STATION, 1899.—Continued.

Day.	FEBRUARY.					MARCH.				
	Max.	Min.	Mean.	Mean t—t.′	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
16.....	80	70	75.0	2.5	89	86	74	79.0	4.0	83
17.....	76	72	74·5	1.5	93	85	76	79.0	3.5	85
18.....	80	74	76.0	2.0	91	84	72	77.5	4.5	80
19.....	83	72	76.5	2.5	89	87	74	79.5	4.0	83
20.....	82	73	77.0	2.5	89	86	75	79.5	3.5	85
21.....	79	74	76.5	2.0	91	87	73	78.5	4.0	83
22.....	80	77	78.0	3.0	87	84	73	78.0	4.0	83
23.....	85	77	79.5	3.5	85	87	74	79.5	5.0	79
24.....	79	73	76.0	3.5	85	86	72	79.5	5.5	77
25.....	83	74	77.5	3.5	85	86	71	78.5	4.5	81
26.....	79	73	76.0	2.0	91	90	73	80.5	6.0	75
27.....	85	74	78.5	3.5	85	....	....	....	....	....
28.....	83	71	76.5	3.5	85	90	74	81.5	6.0	76
29.....	....	....	....	....	....	89	76	81.5	5.5	78
30.....	....	....	....	....	....	89	73	81.0	5.5	78
31.....	....	....	....	....	....	79	75	78.0	2.0	91

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS.

Month.	TEMPERATURE.			Mean relative humidity.	Month.	TEMPERATURE.			Mean relative humidity.
	Max.	Min.	Mean.			Max.	Min.	Mean.	
1898.					September .	90	71	78.6	87.4
February...	90	67	75.5	87.2	October....	90	71	78.2	87.4
March.	90	69	76.7	84.8	November..	88	68	77.0	90.4
April	89	66	76.8	85.3	December ..	86	65.2	75.6	89.0
May	89	71	77.8	87.8	1899.				
June.....	89	71	77.7	90.0	January....	86	66.0	75.2	90.7
July.....	89	71	77.1	92.0	February...	86	64.0	76.0	87.6
August	87	70	77.5	91.0	March.....	90	68.0	77.1	85.0

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1898.
Observed at 7 A. M., 12 M. and 7 P. M.

Day.	FEBRUARY.					MARCH.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1.....	80	72	77	3.0	87	82	70	75	2.5	89
2.....	79	72	75	1.5	93	84	71	77	2.5	89
3.....	76	73	74	1.5	93	89	70	79	4.0	83
4.....	79	69	75	2.5	89	81	73	76	1.0	95
5.....	....	....	....	....	....	82	73	77	2.0	91
6.....	....	....	....	....	....	84	74	77	2.5	89
7.....	....	....	....	....	....	83	73	76	2.0	91
8.....	....	....	....	....	....	85	72	77	3.0	87
9.....	....	....	....	....	....	78	73	75	2.0	91
10.....	....	....	....	....	....	....	....	....	....	....
11.....	81	72	76	2.5	89	....	....	....	....	....
12.....	80	72	76	2.5	89	86	70	77	3.5	85
13.....	81	73	77	3.0	87	89	69	78	4.0	83
14.....	....	....	....	....	....	88	70	78	4.0	83
15.....	....	....	....	....	....	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1898.—Continued.

Day.	February.					March.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean	Mean t−t′.	Relative humidity.
16	....	....	....	....	....	89	70	77	4.0	83
17	....	....	....	....	....	....	....	....	....	....
18	....	....	....	....	....	88	69	77	5.0	78
19	....	....	....	....	....	....	....	....	....	....
20	....	....	....	....	....	90	70	78	6.0	75
21	90	70	77	5.0	78	87	71	77	4.5	80
22	88	69	76	4.5	80	81	71	75	3.5	84
23	80	70	74	2.5	88	85	71	76	3.5	84
24	86	67	76	4.0	82	79	71	75	2.0	91
25	78	72	74	1.5	93	....	....	....	....	....
26	80	72	74	2.0	91	86	71	77	3 5	85
27	83	70	75	3.5	84	82	73	76	3.5	85
28	84	70	76	3.5	85	85	69	77	4.5	80
29	....	....	....	....	....	87	70	77	5.5	76
30	....	....	....	....	....	84	69	77	5.0	78
31	....	....	....	....	....	82	72	77	3.5	85

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1898.

Day.	April.					May.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	....	....	....	....	....	78	71	75	1.5	93
2	89	71	79	6.5	73	82	72	77	2.5	89
3	84	69	77	4.5	80	86	72	79	4.5	81
4	79	71	75	3.0	87	84	71	77	3.5	85
5	75	71	73	1.0	95	82	72	76	2.0	91
6	85	75	79	3.0	87	....	73	....	....	....
7	85	74	78	2.5	89	84	73	79	3.0	89
8	86	71	78	4.5	81	82	73	78	2.5	89
9	....	....	....	....	....	84	77	80	4.0	83
10	81	72	76	2.5	89	82	72	77	2.0	91
11	79	73	76	1.5	93	76	75	76	1.0	95
12	85	72	78	3.5	85	86	73	79	3.5	85
13	86	70	78	4.5	81	84	72	78	3.5	85
14	79	70	75	2.5	89	....	73	....	....	....
15	86	66	76	4.5	80	85	74	78	2.5	89
16	....	....	....	....	....	80	73	76	2.0	91
17	79	73	76	1.5	93	82	73	78	1.5	93
18	85	70	77	3.5	85	83	73	78	2.5	89
19	85	71	77	4.0	83	89	74	79	4.0	83
20	87	69	77	4.5	80	84	73	77	2.5	89
21	88	73	79	4.5	81	83	73	77	2.5	89
22	79	68	74	1.5	93	80	73	76	2.0	91
23	....	....	....	....	....	77	71	74	1.5	93
24	87	72	79	4.5	81	85	72	79	3.5	85
25	87	70	78	4.5	81	84	73	79	3.5	85
26	81	71	75	2.5	89	86	73	79	4.5	81
27	79	71	75	1.5	93	88	73	79	3.5	85
28	85	70	77	4.0	83	85	73	78	3.0	87
29	88	69	78	4.5	81	86	76	80	3.0	87
30	....	....	....	....	....	86	75	79	3.0	87
31	....	....	....	....	....	86	75	79	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1898.

Day.	JUNE.					JULY.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	79	73	76	1.5	93	81	73	77	1.5	93
2	87	72	79	4.0	83	79	72	75	1.5	93
3	87	72	79	4.5	81	85	72	78	2.5	89
4	81	72	76	1.5	93	84	74	78	2.0	91
5	86	74	78	3.0	87	78	72	75	1.0	95
6	87	74	80	3.5	85	82	72	77	2.5	89
7	88	75	81	3.0	86	....	....	....	....	....
8	86	74	80	3.0	87	....	....	....	....	....
9	85	74	79	2.0	91	....	....	....	....	....
10	88	75	80	3.0	87	....	....	....	....	....
11	78	75	76	0.5	98	....	....	....	....	....
12	83	73	77	2.5	89	....	....	....	....	....
13	80	74	76	1.5	93	89	74	80	4.0	83
14	....	....	....	....	....	82	74	78	2.0	91
15	82	72	78	2.5	89	89	75	81	4.0	84
16	81	71	77	1.5	93	86	75	80	2.5	89
17	81	75	79	2.0	91	81	75	78	1.5	93
18	88	75	79	3.5	85	84	75	79	1.5	94
19	89	73	79	4.0	83	81	72	76	1.5	93
20	81	73	76	1.5	93	78	74	75	1.5	93
21	....	....	....	....	....	74	73	74	1.0	95
22	....	....	....	....	....	76	72	75	1.0	95
23	79	74	76	1.5	93	80	74	77	1.5	93
24	79	73	76	1.0	95	82	74	78	1.5	93
25	79	73	76	1.5	93	79	74	76	1.5	93
26	81	75	77	1.0	95	80	75	76	1.5	93
27	78	73	75	1.5	93	83	71	77	1.5	93
28	81	73	76	1.5	93	79	73	77	1.5	93
29	83	70	76	2.0	91	79	74	76	1.0	95
30	86	73	79	2.5	89	79	73	76	1.5	93
31	....	....	....	....	....	80	74	78	1.5	93

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1898.

Day.	AUGUST.					SEPTEMBER.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	81	73	77	1.5	93	85	74	79	3.5	85
2	78	73	75	1.0	95	82	74	77	2.0	91
3	87	73	79	3.5	85	82	74	78	1.0	96
4	....	....	....	....	....	86	74	78	2.5	89
5	....	....	....	....	....	88	74	81	3.0	88
6	78	73	76	1.0	95	82	73	77	1.5	93
7	77	73	75	1.0	95	80	74	76	1.5	93
8	85	73	80	2.5	89	81	75	77	1.5	93
9	79	74	76	1.5	93	84	74	78	2.5	89
10	85	73	79	3.5	85	88	74	79	3.0	87
11	81	73	77	2.5	89	79	74	76	1.5	93
12	82	75	79	1.0	96	79	72	76	1.0	95
13	82	74	77	1.0	95	87	73	79	3.0	87
14	84	72	77	1.5	93	....	....	....	....	....
15	82	72	78	1.5	93	90	72	79	4.5	81

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1898.—Continued.

Day.	August.					September.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
16	86	75	79	2.5	89	83	73	78	1.5	93
17	86	73	79	2.5	89	88	74	81	4.5	82
18	87	70	75	2.0	91	89	73	80	3.5	85
19	87	72	78	3.5	85	82	79	79	3.0	87
20	82	73	76	2.5	89	84	73	77	2.5	89
21	82	74	77	1.5	93	86	71	78	3.0	87
22	85	73	79	2.5	89	86	72	77	4.0	83
23	81	74	77	1.5	93	84	72	78	3.0	87
24	82	74	77	2.0	91	86	73	79	3.0	87
25	82	74	78	1.5	93	87	72	79	5.0	79
26	86	75	79	2.5	89	90	73	80	4.0	83
27	85	75	78	3.0	87	85	74	78	2.5	89
28	....	....	....	....	....	90	74	81	4.5	82
29	84	75	78	2.0	91	90	75	82	4.5	82
30	79	71	76	1.5	93	90	75	82	5.0	80
31	84	76	80	2.5	89	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1898.

Day.	October.					November.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	88	72	79	4.0	83	85.3	74.0	78.5	4.0	83
2	90	72	80	3.5	85	86.5	74.0	79.0	5.0	79
3	81	73	77	2.5	89	86.0	70.0	77.5	3.5	85
4	84	71	78	3.5	85	83.5	73.0	78.0	2.0	91
5	85	73	78	2.5	89	82.0	74.0	79.0	2.5	89
6	84	72	78	2.5	89	81.0	75.0	77.5	1.5	93
7	89	73	80	4.5	81	81.5	73.0	77.0	1.0	95
8	79	75	77	1.0	95	88.0	73.0	80.0	3.5	85
9	84	75	78	2.5	89	85.0	73.0	78.0	2.5	89
10	88	74	79	4.0	83	79.5	74.5	77.5	1.0	95.5
11	90	73	80	4.5	81	84.8	75.0	78.5	2.5	89
12	86	74	79	3.5	85	79.5	74.5	77.5	1.0	95.5
13	81	74	76	1.5	93	76.3	74.0	74.5	1.0	95
14	80	74	76	1.5	93	83.0	72.3	77.5	2.0	91
15	84	74	77	2.5	89	79.0	73.0	75.5	0.5	98
16	85	72	78	5.0	79	74.5	72.3	73.5	0.5	98
17	87	76	80	3.5	85	79.0	73.0	75.5	1.5	93
18	88	72	78	3.0	87	81.0	71.5	76.0	2.0	91
19	86	73	78	2.5	89	82.0	69.5	75.5	1.5	93
20	89	75	81	3.5	86	77.0	71.0	74.5	1.5	93
21	89	74	81	4.0	84	85.0	72.0	77.5	2.0	91
22	89	75	81	4.0	84	85.2	71.0	77.0	4.0	83
23	84	74	78	2.5	89	86.2	68.0	77.0	4.0	83
24	79	74	77	1.5	93	85.0	70.0	76.5	2.5	89
25	76	74	75	1.0	95	79.0	73.0	76.5	1.5	93
26	76	72	74	1.0	95	83.0	73.0	77.5	2.0	91
27	83	73	77	3.5	85	78.0	74.0	76.5	1.5	93
28	85	76	79	....	....	81.0	74.0	77.5	1.5	93
29	....	....	....	....	....	86.7	72.5	78.5	3.0	87
30	....	....	....	....	....	79.0	69.0	75.0	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1898-9.

Day.	December, 1898.					January, 1899.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1.....	77.5	73.0	75.5	0.9	95	84.5	72.5	77.5	3.0	87
2.....	83.0	72.5	78.0	1.9	91	83.0	72.0	77.5	3.0	87
3.....	84.0	73.0	78.0	2.3	89	81.0	72.0	76.0	2.0	91
4.....	86.0	73.0	79.0	3.0	87	81.0	71.0	75.5	1.5	93
5.....	80.0	71.8	74.9	1.9	91	80.0	72.0	75.5	1.5	93
6.....	79.0	70.0	75.3	2.0	91	79.0	70.0	74.5	1.5	93
7.....	86.0	72.0	78.6	3.9	83	79.0	70.0	74.0	1.5	93
8.....	78.0	70.3	74.7	1.8	91	78.5	71.0	75.0	2.0	91
9.....	85.0	73.0	78.0	3.0	87	79.5	72.0	75.5	1.5	93
10.....	76.0	73.0	75.0	1.7	93	79.0	71.0	75.0	2.0	91
11.....	79.3	71.0	74.7	1.7	93	77.0	71.0	74.5	1.0	95
12.....	83.3	71.0	76.7	3.1	87	75.0	73.0	74.5	1.0	95
13.....	82.0	72.0	76.3	2.3	89	83.0	71.0	76.5	2.0	91
14.....	81.0	66.8	74.9	3.1	87	78.0	71.0	74.5	1.0	95
15.....	80.0	68.0	75.4	2.9	87	80.0	71.0	76.5	3.5	85
16.....	78.0	72.5	74.7	1.6	93	78.0	72.0	75.5	2.0	91
17.....	80.5	71.0	76.1	2.5	89	81.0	69.0	75.5	2.0	91
18.....	81.5	69.0	75.6	2.6	89	79.5	72.0	76.0	2.0	91
19.....	85.0	69.0	77.0	4.4	80	81.0	69.0	75.5	3.0	87
20.....	82.5	67.0	76.0	3.5	85	78.0	68.5	73.5	1.5	93
21.....	83.5	69.0	76.1	3.3	85	78.0	69.0	76.5	1.0	95
22.....	81.0	68.0	74.0	2.4	88	80.0	67.0	73.5	1.0	95
23.....	84.0	68.0	75.6	2.8	87	81.0	71.0	75.5	1.5	93
24.....	84.0	66.5	74.3	3.5	84	77.0	71.0	74.5	2.0	91
25.....	85.0	65.2	74.7	3.6	84	82.0	70.0	75.5	2.0	91
26.....	81.5	66.5	74.0	2.7	88	80.0	70.0	75.0	2.5	89
27.....	77.0	68.0	72.7	1 2	95	81.0	68.0	75.0	2.0	91
28.....	79.0	70.0	74.3	2.0	91	86.0	68.0	76.0	4.0	82
29.....	79.0	69.0	74.3	1.2	95	82.0	66.0	73.0	2.5	88
30.....	79.0	70.5	75.1	1.1	95	84.0	69.5	75.5	3.5	84
31.....	80.0	70.0	75.6	1.8	91	82.0	67.0	74.0	2.5	88

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1899.

Day.	February.					March.				
	Max.	Min.	Mean.	Mean t—t.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1.....	80.0	70.5	75.5	2.5	89	79.5	71.5	75.5	2.0	91
2.....	84.5	69.0	76.0	3.5	85	84.5	68.0	76.0	4.0	82
3.....	86.0	67.0	76.5	4.5	80	78.0	73.0	75.0	1.5	93
4.....	82.0	71.0	76.0	3.5	85	83.0	71.0	76.0	2.0	91
5.....	82.0	70.0	75.5	3.0	87	87.0	68.0	77.5	5.0	78
6.....	77.0	69.5	73.5	1.0	95	85.0	71.0	76.0	3.5	85
7.....	86.0	72.0	78.5	3.5	85	81.0	69.0	74.5	3.0	86
8.....	85.0	70.0	77.0	3.5	85	78.0	69.0	73.0	2.0	91
9.....	83.0	73.0	76.5	3.5	85	83.5	70.0	76.0	4.0	82
10.....	84.0	71.0	77.5	3.5	85	84.5	69.0	75.5	4.0	82
11.....	83.0	73.0	77.5	2.5	89	86.0	68.5	75.5	4.0	82
12.....	....	74.0	....	....	....	77.5	71.0	74.0	1.0	95
13.....	81.5	70.0	74.5	2.5	88	82.0	73.0	76.5	1.5	93
14.....	77.0	64.0	70.5	3.0	86	83.5	74.0	78.5	2.5	89
15.....	79.0	69.5	74.0	1.5	93	84.5	72.0	76.5	2.5	89
16.....	81.0	68.5	75.0	1.5	93	87.0	73.5	79.0	4.0	83
17.....	78.5	71.5	75.0	1.5	93	83.0	71.5	76.5	2.5	89
18.....	79.5	72.0	76.0	2.0	91	86.5	70.0	77.5	3.5	85
19.....	83.0	71.0	76.5	2.5	89	88.0	70.0	79.5	4.5	81
20.....	81.5	72.0	76.5	2.0	91	86.0	72.5	78.0	3.0	87

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP SABALOS, 1899.—Continued.

Day.	February.					March.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
21.....	82.0	71.0	76.5	2.0	91	87.0	72.0	78.5	4.0	83
22.....	83.0	70.0	76.5	3.0	87	84.5	72.0	77.5	3.0	87
23.....	86.0	71.0	78.0	3.5	85	87.0	72.0	78.5	4.0	83
24.....	80.0	72.0	76.0	2.5	89	86.0	68.0	77.5	5.0	78
25.....	83.0	72.0	76.5	2.5	89	87.5	72.0	78.5	4.0	83
26.....	83.5	68.5	76.5	3.0	87	88.0	69.0	77.5	4.0	83
27.....	83.0	71.0	76.5	3.0	87	86.5	72.5	78.5	4.0	83
28.....	82.0	71.0	76.5	3.5	85	88.0	72.0	79.5	5.0	79
29.....	....	....	....	....	....	88.5	73.5	80.0	4.5	81
30.....	....	....	....	....	....	90.0	72.0	80.5	5.5	77
31.....	....	....	....	....	....	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT SAN CARLOS RIVER STATION.

Month.	Temperature.			Mean relative humidity.	Month.	Temperature.			Mean relative humidity.
	Max.	Min.	Mean.			Max.	Min.	Mean.	
1898.					1898.				
January.	86	69	75.8	92.0	May	95	72	80.7	88.5
February ...	89	66	74.5	88.1	June.....	93	73	79.9	87.2
March.....	88	68	77.0	86.8	July	88	71	77.6	89.3
April	91	70	77.6	86.5	August.....	88	72	78 0	89.2

TEMPERATURE AND RELATIVE HUMIDITY AT SAN CARLOS RIVER STATION, 1898.

Day.	January.					February.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	....	....	....	....	....	78.0	71.0	74.0	2.0	91
2.....	....	....	....	....	....	72.0	69.0	70.3	1.2	95
3.....	....	....	....	....	....	76.5	69.0	72.3	0.8	95
4.....	....	....	....	....	....	73.0	69.5	71.0	0.7	98
5.....	....	....	....	....	....	76.5	68.0	71.3	2.0	91
6.....	....	....	....	....	....	80.0	71.0	74.3	3.2	86
7.....	....	....	....	....	....	80.0	66.0	74.6	3.3	84
8.....	....	....	....	....	....	87.0	74.0	80.0	5.0	79
9.....	....	....	....	....	....	79.0	72.0	75.0	2.0	91
10.....	....	....	....	....	....	88.5	71.0	77.8	3.8	83
11.....	....	....	....	....	....	89.0	70.0	77.6	4.0	83
12.....	81.0	75.0	77.3	2.0	91	78.0	71.0	73.6	1.6	93
13.....	77.5	74.0	75.3	1.3	93	83.0	71.0	75.3	3.8	82
14.....	81.0	76.0	78.0	2.5	89	77.0	68.0	72.6	2.5	88
15.....	77.0	74.0	75.0	1.4	93	83.0	67.0	76.0	4.7	80
16.....	76.0	74.0	74.6	0.8	95	81.0	68.0	73.6	2.0	91
17.....	76.0	74.0	75.0	1.0	95	81.0	67.0	73.6	2.8	86
18.....	77.0	73.5	74.8	1.3	93	87.5	69.0	77.1	4.8	78
19.....	79.0	73.0	76.3	1.3	93	82.0	71.0	75.6	2.0	91
20.....	80.5	75.0	77.1	1.5	93	80.0	71.0	74.6	1.0	95
21.....	77.0	73.0	74.6	1.3	93	86.0	72.0	78.0	4.0	83
22.....	80.5	72.0	76.1	1.5	93	81.0	72.0	75.3	2.3	89
23.....	86.0	72.0	78.3	0.8	96	84.0	68.0	74.6	3.6	84
24.....	81.5	72.0	77.1	3.1	87	82.0	71.0	75.3	3.0	87
25.....	79.0	71.5	75.6	1 3	93	82.0	69.0	74.6	2.3	88
26	79.0	73 0	76.0	2.0	91	73.0	70.0	71.6	1.6	93
27.....	81.0	73.0	76.6	2.6	89	76.0	70.0	72.6	1.3	93
28.....	80.0	79.5	74.0	1.9	91	81.0	71.0	75.3	2.7	89
29.....	80.0	70.0	74.3	2.0	91	....	....	....	....	....
30.....	79.0	70.5	75.8	2.5	89	....	....	....	....	....
31.....	79.0	74.0	73.5	1.7	93	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT SAN CARLOS RIVER STATION, 1898.

Day.	MARCH.					APRIL.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	81.0	71.0	75.0	2.4	89	83.0	71.0	77.0	2.7	89
2.....	86.0	69.0	76.3	3.2	87	85.0	71.0	76.3	3.3	85
3.....	87.5	73.0	79.5	3.9	83	82.0	75.0	78.0	2.7	89
4.....	79.0	75.0	77.1	1.3	93	83.0	72.0	76.3	2.7	89
5.....	82.5	75.0	78.1	2.1	91	82.0	73.0	76.6	1.3	93
6.....	82.0	73.0	77.1	2.8	87	82.0	74.0	77.3	2.0	91
7.....	82.0	72.0	76.5	2.9	87	76.0	75.0	75.5	1.0	95
8.....	80.5	73.0	76.3	2.2	91	85.0	73.0	77.6	4.3	81
9.....	78.0	72.0	74.8	1.2	95	88.0	74.0	78.6	4.0	83
10.....	82.0	73.0	76.6	1.6	93	84.0	74.0	77.3	4.0	83
11.....	82.0	73.0	76.6	2.6	89	80.0	74.0	76.3	1.7	93
12.....	81.0	73.0	76.0	2.4	89	81.0	74.0	77.3	2.7	89
13.....	84.0	71.0	77.3	3.0	87	87.0	73.0	78.3	3.7	85
14.....	84.0	70.0	77.6	4.0	83	84.0	75.0	78.0	4.4	81
15.....	82.0	71.0	76.6	3.0	87	90.0	72.0	78.0	5.0	79
16.....	86.0	72.0	78.0	4.7	81	84.0	73.0	77.6	3.6	85
17.....	84.0	72.0	77.3	3.3	85	85.0	75.0	79.3	3.3	85
18.....	85.0	71.0	77.3	3.0	87	80.0	75.0	76.6	2.3	89
19.....	81.0	70.0	76.0	2.0	91	84.0	74.0	77.6	3.0	87
20.....	85.0	71.0	77.6	5.0	78	89.0	71.0	78.6	5.0	79
21.....	82.0	72.0	76.0	2.4	89	89.0	75.0	80.0	4.7	81
22.....	88.0	73.0	78.0	3.7	85	78.0	74.0	75.5	1.5	93
23.....	87.0	74.0	79.0	4.7	81	83.0	75.0	78.0	3.5	85
24.....	81.0	75.0	77.3	3.0	87	85.0	73.0	77.0	3.0	87
25.....	78.0	72.0	74.6	1.3	93	88.0	75.0	77.5	2.0	91
26.....	83.0	73.0	77.3	3.0	87	82.0	75.0	77.5	2.0	91
27.....	82.0	72.0	76.3	2.0	91	85.0	72.0	77.0	3.5	85
28.....	82.0	68.0	75.0	1.9	91	87.0	70.0	76.5	3.0	87
29.....	86.0	74.0	78.6	5.0	79	91.0	75.0	81.0	5.5	78
30.....	86.0	75.0	79.6	5.6	77	86.0	73.0	79.0	3.0	87
31.....	88.0	71.0	79.0	5.4	77	....	....	....	....	...

TEMPERATURE AND RELATIVE HUMIDITY AT SAN CARLOS RIVER STATION, 1898.

Day.	MAY.					JUNE.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	83.0	74.0	78.5	1.5	93.5	84.0	73.0	77.5	1.5	93
2.....	87.0	72.0	78.5	3.3	87	91.0	73.5	81.0	4.8	80
3.....	89.0	74.0	80.5	5.0	79.5	91.0	75.0	81.5	4.5	82
4.....	80.0	73.0	76.5	1.5	93	90.5	76.0	81.5	4.0	84
5.....	88.0	75.0	80.5	1.5	94	91.0	78.5	83.0	5.0	80
6.....	89.0	79.0	84.5	2.5	90	92.5	78.0	84.5	5.0	80
7.....	95.0	82.0	88.0	5.0	81	89.0	77.0	82.0	3.5	86
8.....	89.0	80.0	84.5	2.5	90	91.5	77.5	82.5	3.5	86
9.....	93.0	82.0	87.0	3.5	86	91.0	77.0	83.5	4.5	82
10.....	84.0	81.0	82.5	1.0	96	91.0	77.0	82.6	4.8	80
11.....	82.0	80.0	81.0	1.0	96	79.5	75.0	77.0	2.0	91
12.....	91.0	85.0	87.5	4.0	84.5	89.0	73.0	80.5	3.0	87.5
13.....	92.0	78.0	84.5	3.5	86	81.0	76.0	78.0	2.2	91
14.....	80.0	76.0	77.5	1.5	93	81.5	76.5	79.0	2.5	89
15.....	80.0	74.5	76.5	1.0	95	84.5	78.0	80.5	5.0	79.5

TEMPERATURE AND RELATIVE HUMIDITY AT SAN CARLOS RIVER STATION, 1898.—Continued.

Day.	MAY.					JUNE.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
16.....	85.0	73.5	78.0	1.5	93	89.5	76.0	82.0	4.0	84
17.....	85.0	74.0	78.5	2.5	89	89.0	76.5	81.5	3.5	86
18.....	83.0	76.0	78.5	2.0	91	93.0	75.0	81.0	3.0	88
19.....	87.5	75.5	79.5	3.0	87	89.5	74.0	80.5	3.5	86
20.....	85.0	75.0	78.5	2.0	91	83.0	73.0	76.5	2.0	91
21.....	81.0	75.0	77.5	1.5	93	88.0	74.0	79.0	2.5	89
22.....	85.0	74.0	78.5	3.0	87	85.0	73.0	78.5	1.5	93.5
23.....	78.5	75.5	76.5	1.5	93	87.0	74.5	79.1	2.5	89
24.....	91.0	75.0	82.5	6.0	76	80.5	74.0	77.0	1.5	93
25.....	90.0	76.5	82.5	6.5	74	83.0	74.0	77.5	1.5	93
26.....	89.0	76.5	81.5	4.5	82	86.5	74.0	78.5	2.3	89
27.....	91.0	77.0	81.5	3.0	88	77.0	73.0	75.5	1.0	95
28.....	92.0	77.0	82.5	3.5	86	85.0	73.0	77.5	2.0	91
29.....	83.0	76.0	78.6	2.0	91	87.0	73.0	79.0	2.0	91
30.....	86.0	76.0	80.5	2.5	89	87.5	74.0	80.0	3.0	87
31.....	82.0	76.5	79.0	2.0	91	....	....	....	....	...

TEMPERATURE AND RELATIVE HUMIDITY AT SAN CARLOS RIVER STATION, 1898.

Day.	JULY.					AUGUST.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	83.0	76.0	78.5	1.5	93.5	78.0	76.0	77.0	1.0	93
2.....	75.5	73.0	74.5	1.0	95	77.0	73.0	75.0	1.5	93
3.....	83.5	75.5	79.0	3.0	87	83.5	73.0	77.5	3.0	87
4.....	81.0	75.0	77.5	2.0	91	83.0	74.5	77.5	2.5	89
5.....	79.5	73.5	76.5	1.5	93	87.5	73.5	79.0	3.5	85
6.....	85.5	72.5	78.5	3.0	87	87.5	73 5	80.0	3.5	85
7.....	85.0	73.5	79.0	2.5	89	77.0	76.0	76.5	1.5	93
8.....	77.0	74.5	76.0	1.5	93	81.0	74.5	77.0	2.5	89
9.....	82.5	72.0	77.5	2.5	89	77.0	74.0	75.5	1.5	93
10.....	75.0	73.0	74.0	1.5	93	88.0	74.0	80.5	3.5	85.5
11.....	86.5	73.0	78.5	3.0	87	83.5	74.5	78.5	2.5	89
12.....	82.0	73.0	78.0	2.0	91	76.0	74.5	75.0	1.0	95
13.....	88.0	72.5	80.0	3.5	85	85.0	73.0	77.0	2.5	89
14.....	86.5	73.0	79.5	3.5	85	82.0	72.0	77.0	1.5	93
15.....	88.0	74.0	80.1	4.0	83	81.0	73.0	77.0	2.0	91
16.....	88.0	73.5	80.1	3.5	85	84.0	73.0	78.0	2.5	89
17.....	82.5	75.5	78.6	2.5	89	83.5	72.5	78.0	2.5	89
18.....	82.0	76.0	78.5	2.0	91	87.5	73.0	79.5	4.0	83
19.....	84.5	73.0	78.5	3.5	85	85.0	73.5	79.0	3.5	85
20.....	75.5	71.5	74.0	1.0	95	86.0	74.0	79.0	3.5	85
21.....	75.0	73.0	74.0	1.5	93	84.0	75.0	78.0	2.5	89
22.....	85.0	71.5	77.5	3.5	85	87.0	73.0	80.0	3.5	85
23.....	79.5	74.0	76.5	1.5	93	78.0	74.0	76.5	1.5	93
24.....	80.0	74.0	76.5	1.5	93	81.5	73.0	77.5	2.0	91
25.....	76.5	74.0	75.5	1.0	95	86.5	75.0	80.0	2.5	89
26.....	80.5	73.5	77.0	1.5	93	84.0	75.0	79.0	2.5	89
27	84.5	73.5	78.0	2.5	89	86.0	75.0	79.5	3.5	85
28.....	82.0	74.0	78.0	2·5	89	83.0	73.0	77.5	1.5	93
29.....	81.0	74.5	78.0	2.5	89	85.0	74.0	79.5	3.0	87
30.....	86.0	74.0	79.0	4.0	83	84.0	73.0	77.5	2.0	91
31	87.0	73.0	80.0	4.5	81	80.0	74.0	76.5	1.5	93

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION.

Month.	Temperature.			Mean relative humidity.	Month.	Temperature.			Mean relative humidity.
	Max.	Min.	Mean.			Max.	Min.	Mean.	
1898.					1898.				
January.....	83	66	73.9	91.6	September....	91	70	77.5	89.6
February....	85	66	73.3	90.4	October.....	95	71	78.2	89.4
March.....	87	67	75.1	87.6	November....	89	70	76.1	92.0
April	88	66	75.8	88.8	December.....	85	67	75.1	91.0
May	94	72	78.3	90.0	1899.				
June.....	90	71	77.5	90.7	January.....	84.5	67	74.8	93.2
July	89	70	76.6	91.5	February.....	86	68	75.3	91.9
August.....	87	71	77.0	91.4	March.....	91	67	75.6	89.7

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1898.

Day.	January.					February.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1.....	81.0	72.5	75.5	2.5	89	74.0	70.0	72.5	1.2	95
2.....	78.5	69.0	72.3	2.8	87	73.0	69.0	71.0	1.0	95
3.....	76.5	66.5	70.8	1.7	93	78 0	70.0	73.0	2.2	91
4.....	75.0	66.5	70.1	1.3	93	76.0	69.5	72.0	1.0	95
5.....	72.5	68.5	70.3	0.4	98	77.0	68.5	72.6	2.3	88
6.....	74.5	70.5	72.8	0.7	98	79.5	68.5	73.0	3.7	84
7.....	80.5	70.5	74.8	3.2	87	80.0	67.5	72.6	3.6	84
8.....	80.5	70.5	75.1	4.6	80	72.0	70.0	71.1	0.6	98
9.....	79.5	73.0	75.6	2.3	89	....	70.5	....	....	....
10.....	76.0	72.5	74.1	0.5	98	76.0	70.5	73.5	2.7	88
11.....	78.5	....	....	....	....	81.5	72.0	75.6	2.8	89
12.....	82.5	73.0	76.3	1.7	93	76.0	71.0	73.0	1.4	93
13.....	81.5	72.5	76.0	1.4	93	81.0	69.5	74.3	3.5	84
14.....	78.5	70.0	74.3	1.2	95	75.5	69.5	71.6	1.6	93
15.....	78.0	69.5	73.1	1.0	95	82.0	67.0	73.6	3.6	84
16.....	75.0	72.5	73.8	1.2	95	72.0	71.0	71.6	0.8	95
17.....	77.0	70.5	73.6	1.0	95	77.0	66.5	71.6	1.5	93
18.....	....	....	....	....	....	84.5	67.5	75.1	3.1	87
19.....	....	....	....	....	....	82.5	72.0	76.1	2.8	87
20.....	....	....	....	....	....	82.5	71.0	75.1	1.5	93
21.....	....	....	....	....	....	83.5	72.0	76.3	3.3	86
22.....	....	....	....	....	....	80.5	71.0	74.3	1.8	91
23.....	82.5	72.0	75.8	2.3	89	81.0	67.5	73.3	2.7	88
24.....	77.5	70.5	74.0	2.5	88	81.0	70.0	74.3	2.7	88
25.....	78.0	72.0	74.6	1.3	93	78.5	69.5	73.5	1.9	91
26	76.5	72.0	73.6	1.1	95	76.0	70.5	72.3	0.8	95
27.....	81.0	72.5	75.5	3.0	87	74.0	70.5	71.8	0.7	98
28.....	79.0	70.5	74.0	2.0	91	80.5	69.5	74.1	2.3	88
29.....	78.0	70.0	73.6	1.3	95	....	....	....	....	....
30.....	81.5	71.0	74.6	3.8	82	....	....	....	....	....
31.....	....	69.0	....	....	....	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1898.

Day.	MARCH.					APRIL.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	80.0	71.5	74.8	2.2	91	83.0	68.5	75.0	2.5	88
2.....	82.0	68.5	74.6	2.8	86	84.0	69.5	75.0	3.4	84
3.....	86.5	69.5	77.1	2.8	87	82.0	67.5	74.6	2.2	91
4.....	76.0	74.0	75.0	0.9	95	81.5	73.0	76.1	2.0	91
5.....	79.5	73.5	75.6	1.3	93	82.0	73.0	76.5	0.7	98
6.....	78.0	71.0	74.0	1.9	91	....	74.5	....	....	....
7.....	....	70.5	....	....	....	78.5	74.0	75.6	0.5	98
8.....	79.5	72.5	74.8	1.8	91	83.5	70.5	75.8	3.8	82
9.....	78.0	70.5	74.1	1.1	95	83.5	68.0	75.0	3.9	80
10.....	79.0	71.5	74.8	2.0	91	81.5	71.5	75.6	2.8	87
11.....	83.5	71.5	76.1	3.6	85	81.0	72.5	76.0	2.0	91
12.....	80.5	71.5	74.8	2.3	89	85.0	73.5	77.6	2.5	89
13.....	86.5	69.5	76.0	4.0	82	85.5	73.5	77.5	4.0	82
14.....	....	68.0	....	....	....	84.0	70.0	75.3	3.5	85
15.....	82.0	70.0	75.8	2.2	91	86.0	68.0	75.1	4.0	82
16.....	82.5	70.5	75.6	2.8	87	88.0	66.5	75.5	3.5	84
17.....	83.5	70.5	75.3	4.3	81	82.5	70.5	76.3	1.5	93
18.....	82.5	68.5	74.1	3.6	84	79.5	72.5	75.3	1.2	95
19	85.0	67.0	74.8	4.3	80	85.0	72.0	76.6	2.6	89
20.....	85.0	68.0	75.0	4.9	78	85.0	68.5	75.5	4.0	82
21.....	82.0	71.0	75.0	2.2	91	80.0	71.5	74.5	1.9	91
22.....	81.0	71.5	74.8	2.2	91	78.0	72.0	74.3	1.2	95
23.....	86.5	69.0	76.0	4.0	82	86.0	72.5	77.3	2.5	89
24.....	82.5	71.0	76.1	2.5	89	85.5	73.0	77.8	2.7	89
25.....	....	72.0	....	....	....	85.5	72.0	77.5	4.2	83
26.....	82.0	71.5	76.0	3.0	89	81.5	71.0	75.0	1.5	93
27.....	73.0	71.0	72.0	1.7	93	80.0	70.5	74.1	0.8	95
28.....	82.5	68.0	74.1	2.5	88	80.5	68.0	74.0	1.7	93
29.....	83.0	70.0	75.3	3.0	87	87.5	69 5	76.8	4.3	80
30.....	84.0	67.0	74.6	5.0	78	85.0	70.0	77.1	1.1	95
31.....	83.5	70.0	75.6	3.0	87	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1898.

Day.	MAY.					JUNE.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	83.0	74.0	77.6	1.5	93	80.5	73.5	76.3	1.2	95
2.....	82.0	72.5	76.5	1.2	95	87.0	71.5	77.5	4.5	80
3.....	88.0	75.0	79.6	3.5	85	86.0	71.5	77.5	3.0	87
4.....	75.0	72.0	73.8	0.2	98	84.5	73.5	77.6	2.5	89
5.....	83.0	73.0	77.0	1.7	93	87.5	75.0	79.8	3.3	85
6.....	85.5	73.5	78.5	1.9	91	90.0	75.0	81.5	3.2	88
7.....	89.0	74.0	79.8	2.8	87	86.5	75.0	79.8	2.7	89
8.....	87.5	76.5	80.3	3.2	87	85.5	75.5	79.0	2.9	87
9.....	88.0	75.0	80.1	4.1	83	86.5	76.0	80.1	2.8	87
10.....	80.0	74.5	77.1	0.8	95	87.0	75.5	80.1	2.6	89
11.....	80.0	75.5	77.3	0.5	98	82.0	72.5	76.8	1.7	93
12.....	87.0	73.0	78.8	2.7	89	84.5	71.5	77.5	1.4	93
13.....	85.5	74.0	78.6	2.5	89	79.5	74.0	76.0	1.0	95
14.....	84.0	74.5	78.0	1.9	91	77.0	73.0	74.8	1.5	93
15.....	79.5	73.5	76.1	1.1	95	81.0	72.5	76.6	1.3	93

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1898.—Continued.

Day.	MAY.					JUNE.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
16.....	84.5	73.5	78.1	2.1	91	84.0	75.0	78.8	1.3	94
17.....	85.0	74.0	78.3	2.2	91	87.0	75.0	79.5	2.5	89
18.....	82.5	73.5	77.1	1.6	93	87.0	73.0	78.5	1.4	93
19.....	90.5	73.0	79.1	3.5	85	87.5	72.5	78.1	2.8	87
20.....	82.5	72.5	76.1	1.6	93	81.0	73.0	76.0	2.0	91
21.....	84.0	73.0	77.5	1.9	91	84.5	73.0	77.1	2.1	91
22.....	88.0	73.5	79.0	3.2	87	84.5	73.0	77.5	2.0	91
23.....	77.5	73.0	75.3	1.0	95	77.0	73.5	75.0	0.7	93
24.....	92.0	73.5	80.8	4.3	82	78.0	73.5	75.3	0.8	95
25.....	93.5	72.0	81.1	4.6	82	83.0	73.5	77.1	1.6	93
26.....	93.5	73.5	81.3	3.8	84	84.0	73.5	77.0	1.7	93
27.....	88.5	73.0	78.6	3.0	87	77.0	72.0	74.5	0.7	98
28.....	92.0	72.5	80.0	2 7	89	80.5	72.5	75.5	1.4	93
29.....	87.5	75.5	79.5	2.2	91	83.0	71.5	76.1	2.3	89
30.....	87.0	75.5	80.1	2.6	89	85.5	72.5	78.0	3.0	87
31.....	82.0	75.5	77.8	2.3	89	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1898.

Day.	JULY.					AUGUST.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	....	73.0	....	....	....	79.5	76.0	77.1	1.3	93
2.....	76.5	72.0	74.6	0·3	98	76.5	72.5	74.0	0.7	98
3.....	82.5	72.5	77.1	2.1	91	81.5	72.5	76.3	1.8	91
4.....	80.5	74.5	76.6	1.6	93	83.5	73.5	77.1	2.3	89
5.....	81.0	72.5	75.5	1.3	93	84.0	73.0	77.6	2.5	89
6.....	86.0	72.0	78.0	2.0	91	85.0	73.0	78.3	2.3	89
7.....	85.0	73.0	78.3	2.7	89	75.5	75.0	75.1	0.6	98
8.....	89.0	73.5	78.6	1.1	96	83.5	74.0	77.3	2.3	89
9.....	81.5	71.5	76.5	2.4	89	76.5	74.0	75.0	0.5	98
10.....	77.0	72.5	74.1	1.1	95	85·5	73.5	79.0	2.7	89
11.....	84.5	72.5	77.0	2.2	91	76.0	74.0	75.3	0.5	98
12.....	87.0	73.0	79.1	2.8	87	78.5	74.5	75.8	0.7	98
13.....	88.0	73.5	79.5	3.2	87	83.5	72.0	76.0	2.9	87
14.....	86.0	74.0	78.8	3.0	87	82.5	71.0	76.3	3.3	85
15.....	87.0	73.0	78.3	3.3	85	81.5	72.5	76.5	1.7	93
16.....	85.0	72.5	78.0	2.4	89	84.0	72.5	77.3	2.7	89
17.....	80.0	75.0	77.0	1.5	93	80.0	72.0	75.3	1·2	95
18.....	80.0	73.5	76.3	1.0	95	85.0	71.5	77.1	3.3	85
19.....	83.0	72.0	76.6	2.6	89	85.5	71.5	78.0	3.0	87
20.....	79.0	70.5	74.5	2.5	88	86.0	73.5	78.5	3.4	85
21.....	79.5	71.5	74.3	2.3	88	80.5	73.5	76.0	1.9	91
22.....	81.0	70.0	74.8	1.8	91	86.0	72.5	78.0	3.0	87
23.....	78.5	72.5	75.1	1.1	95	76.5	73.0	74.8	0.3	98
24	78.5	73.5	75.1	0.8	95	82.0	73.0	77.0	1.2	95
25.....	75.5	73.0	74.1	0.3	98	87.0	75.0	79.3	3.0	87
26.....	75.5	73.0	74.5	0.5	98	84.0	74.5	78.1	2.3	89
27.....	83.0	71.5	76.3	2.5	89	81.0	74.0	76.6	1.6	93
28.....	82.5	73.5	77.3	2.0	91	83.0	72.5	77.1	2.5	89
29.....	81.0	73.0	76.6	1.3	93	80.0	74·0	76.6	1.1	95
30.....	79.0	74.0	76.3	1.2	95	83.0	72.5	77 1	2.0	91
31.....	87.0	73.0	79.3	3.0	87	80.5	74.0	77.0	1.0	95

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1898.

Day.	SEPTEMBER.					OCTOBER.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	79.5	71.5	74.8	1.1	95	95.0	74.0	81.0	3.0	88
2.....	86.0	71.0	78.3	2.7	89	88.0	72.0	79.0	4.0	83
3.....	....	75.0	....	....	....	84.0	74 0	78.0	2.5	89
4.....	81.0	74.0	76.6	1.0	95	84.0	72.0	77.0	2.5	89
5.....	86.0	72.0	78.3	2.4	89	78.0	73.0	75.0	1.5	93
6.....	83.0	73.5	77.6	1.4	93	85.0	71.0	78.0	2.5	89
7.....	79.0	74.0	76.3	1.5	93	90.0	72.0	80.0	4.0	83
8.....	77.0	72.5	75.0	1.2	95	90.0	75.0	81.0	3.0	88
9.....	85.5	72.5	78.0	3.2	87	90.0	73.0	80.0	3 5	85
10.....	86.5	72.5	77.5	3.0	87	91.0	72.0	80.0	3.5	85
11.....	83.5	71.0	77.0	2.5	89	92.0	73.0	81.0	4.0	84
12.....	87.5	72.0	78.0	3.0	87	86.0	72.0	78.0	2.5	89
13.....	79.0	70.5	74.3	1.3	93	81.0	74.0	77.0	1.5	93
14.....	76.5	71.5	74.6	0.8	95	78.0	72.0	75.0	1.5	93
15..... ..	86.5	73.5	79.3	3.3	85	78.0	73.0	76.0	1.0	95
16.....	87.5	73.5	79.6	3.8	83	86.0	74.0	79.0	2.0	91
17.....	87.5	73.0	79.3	4.3	81	87.0	74.0	79.0	3.0	87
18.....	85.5	74.5	79.1	3.1	87	88.0	72.0	77.0	3.0	87
19.....	83.0	75.0	77.8	2.8	87	89.0	72.0	80.0	2.5	89
20.....	84.5	73.5	77.6	2.8	87	87.0	74.0	80.0	2.5	89
21.....	85.0	73.0	77.6	2.8	87	90.0	72.0	78.0	3.0	87
22	85.0	72.0	76.5	3.2	87	86.0	74.0	80.0	2.5	89
23.....	83.0	71.0	76.3	1.7	93	77.0	75.0	76.0	0.5	98
24.....	....	71.5	....	....	....	82.0	73.0	77.0	2.0	91
25	86.0	73.0	77.3	2.2	91	77.0	74.0	75.0	1.0	95
26.....	74.5	73.0	73.7	0.7	98	78.0	73.0	75.0	1.0	95
27.....	88.0	72.5	78.5	3.0	87	85.0	72.0	78.0	2.0	91
28.....	88.0	72.0	80.0	2.5	89	85.0	72.0	78.0	2.5	89
29.....	91.0	75.0	81.0	2.5	90	90.0	72.0	80.0	3.5	85
30..... ..	91.0	73.0	81.0	2.5	90	79.5	73.5	76.0	1.2	95
31.....	....	....	....	....	....	89.5	72.5	80.0	2.9	87

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1898.

Day.	NOVEMBER.					DECEMBER.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	89.0	74.0	79.6	3.3	85	77.5	73.0	75.0	1.0	95
2.....	87.5	70.0	78.6	3.5	85	83.5	73.5	78.0	2.0	91
3.....	86.0	71.5	77.8	2.8	87	84.5	73.0	77.5	2.3	89
4.....	81.0	73.0	76.6	1.0	95	83.0	75.0	78.0	2.0	91
5.....	83.0	73.5	77.3	1.8	91	82.5	72.0	75.5	1.5	93
6.....	77.5	74.5	75.5	0.9	95	77.5	72.5	75.0	1.0	95
7.....	79.0	73.5	76.0	0.9	95	82.5	71.5	76.0	2.5	89
8.....	80.0	74.5	76.6	1.8	91	79.0	72.5	75.0	1.5	93
9.....	78.5	73.5	75.5	1.2	95	81.0	71.5	75.5	1.0	95
10.....	76.5	73.5	75.0	0.7	98	78.0	72.0	74.5	1.0	95
11.....	82.0	73.5	77.1	2.0	91	76.0	70.5	72.5	0.5	98
12.....	80.5	74.0	77.3	1.0	95	84.5	70.0	76.0	2.5	89
13.....	75.5	74.0	74.6	0.8	95	77.0	71.5	73.5	1.0	95
14.....	83.0	73.0	77.0	2.2	91	83.5	67.5	74.5	3.0	86.5
15.....	78.5	73.0	75.1	1.1	95	83.0	67.5	74.5	2.5	88.5

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1898.—Continued.

Day.	November.					December.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
16.....	73.5	73.0	73.1	0.3	98	79.5	71.0	74.5	1.5	93
17.....	76.0	72.5	73.8	0.8	95	82.0	70.0	74.5	2.0	91
18.....	74.0	72.5	73.1	0.6	98	78.5	69.5	73.5	1.0	95
19.....	82.0	72.5	75.8	2.3	89	85.0	68.5	75.5	3.0	87
20.....	77.0	71.0	73.8	1.7	93	84.0	68.5	75.0	2.0	91
21.....	84.0	70.5	76.0	3.2	87	84.0	69.5	75.5	2.5	89
22.....	83.5	71.5	76.3	2.7	89	83.0	68.0	75.0	2.5	89
23.....	81.0	70.0	75.0	2.5	89	84.0	70.0	76.0	3.0	87
24.....	80.5	72.0	75.1	1.5	93	83.0	67.0	74.0	2.5	88
25.....	80.5	72.0	75.8	2.0	91	83.5	67.5	75.0	2.5	89
26.....	84.0	72.5	77.3	2.0	91	83.0	70.5	75.0	2.5	89
27.....	83.5	73.5	77.5	1.7	93	80.0	67.0	73.5	2.0	91
28.....	82.5	73.5	77.5	2.0	91	82.0	68.0	75.0	2.5	89
29.....	82.0	74.5	77.1	1.8	91	82.0	68.5	75.0	2.0	91
30.....	82.0	71.5	75.8	2.5	89	82.0	71.0	76.5	2.0	91
31.....	....	....	....	....	....	82.0	71.5	76.0	2.0	91

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1899.

Day.	January.					February.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	80.0	71.5	75.0	1.0	95	78.5	72.5	74.5	1.0	95
2.....	81.0	72.0	75.5	1.5	93	83.5	69.0	75.0	2.5	89
3.....	81.5	72.0	75.5	1.5	93	82.0	71.0	75.5	2.0	91
4.....	79.0	71.0	75.0	1.5	93	80.0	71.5	75.5	2.0	91
5.....	79.0	71.5	74.5	1.5	93	81.0	70.5	75.0	2.0	91
6.....	79.0	70.5	74.0	1.5	93	80.0	70.5	74.5	1.0	95
7.....	77.0	71.0	73.5	1.5	93	83.5	71.0	76.0	2.0	91
8.....	77.5	69.5	73.0	1.0	95	86.0	71.0	77.0	2.0	91
9.....	81.0	70.0	75.5	1.5	93	83.0	72.0	76.0	2.5	89
10.....	80.5	71.5	75.5	1.5	93	79.0	71.5	75.0	1.5	93
11.....	77.5	72.0	74.0	1.0	95	76.0	71.0	74.0	0.5	98
12.....	75.5	72.5	74 0	0.5	98	76.0	73.0	74.5	0.5	98
13.....	82.5	72.0	76.5	1.5	93	78.0	71.0	73.5	2.0	91
14.....	78.0	72.0	74.5	1.0	95	73.5	69.5	71.0	1.5	93
15.....	80.5	72.0	75.5	1.0	95	78.0	68.0	72.5	1.0	95
16.....	79.0	72.0	75.0	1.5	93	79.0	68.5	73.5	1.5	93
17.....	80.0	71.0	75.0	1.0	95	80.0	70.0	74.5	1.5	93
18.....	78.5	72.5	75.0	1.0	95	78.0	72.0	75.0	1.0	95
19.....	80.0	72.0	75.5	1.5	93	82.5	72.0	75.5	2.0	91
20.....	76.5	70.5	73.5	1.0	95	83.0	71.0	76.5	2.5	89
21.....	79.0	70.5	74.0	1.5	93	81.5	72.0	76.0	1.5	93
22.....	81.0	70.0	73.5	1.5	93	83.0	72.5	77.0	2.5	89
23.....	81.5	71.5	76.0	2.0	91	83.0	72.0	76.5	2.5	89
24.....	81.0	72.5	75.5	1.0	95	80.0	71.0	75.0	1.5	93
25.....	79.0	72.0	75.0	1.5	93	82.0	71.0	76.5	2.5	89
26.....	83.0	70.5	75.5	2.0	91	83.0	71.5	76.5	2.0	91
27.....	84.5	69.5	76.0	2.0	91	83.0	72.5	76.5	2.5	89
28.....	83.5	69.0	75.0	2.5	89	83.0	72.0	76.5	2.5	89
29.....	79.0	69.0	74.0	1.5	93	....	....	....	....	....
30.....	84.0	68.5	75.0	3.0	87	....	....	....	....	....
31.....	79.5	67.0	73.5	2.0	91	....	...	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT OCHOA STATION, 1899.

	MARCH.										
Day.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Day.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	77.0	70.0	72.5	1.0	95	17.....	81.5	71.0	75.0	1.5	93
2.....	82.0	68.0	74.0	1.5	93	18.....	81.5	70.5	75.0	1.5	93
3.....	79.0	71.0	74.0	1.0	95	19.....	91.0	70.5	79.0	1.5	93
4.....	85.0	70.0	76.0	2.0	91	20.....	88.5	70.5	78.0	4.0	83
5.....	86.5	69.5	76.5	2.5	89	21.....	88.0	71.0	78.5	4.5	81
6.....	84.0	70.5	76.0	2.5	89	22.....	81.5	71.5	76.0	3.5	85
7.....	73.0	69.0	71.5	0.5	98	23.....	86.0	70.0	76.0	3.0	87
8.....	78.0	69.0	72.5	0.5	98	24.....	85.5	69.5	76.0	3.0	87
9.....	82.5	69.5	74.5	2.0	91	25.....	86.5	68.5	76.0	5.0	78
10.....	83.0	68.0	74.0	2.5	88	26.....	84.5	68.0	75.5	4.0	83
11.....	84.5	67.0	74.5	3.0	86	27	84.0	72.5	77.0	3.0	87
12.....	78.0	72.0	74.5	1.0	95	28.....	86.0	70.5	77.0	4.0	83
13.....	80.0	72.0	75.5	1.0	95	29.....	86.5	71.0	77.0	4.0	83
14.....	76.0	73.0	74.0	1.5	95	30.....	84.5	70.5	76.5	2.5	89
15.....	87.0	72.5	77.5	1.5	93	31.....	80.0	73.0	76.0	1.5	93
16.....	83.0	72.0	76.0	2.0	91						

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO.

Month.	TEMPERATURE.			Mean relative humidity.	Month.	TEMPERATURE.			Mean relative humidity.
	Max.	Min.	Mean.			Max.	Min.	Mean.	
1898.					1898.				
January.....	86	65	74.1	94.7	July	85	73	78.1	92.1
February.....	84	66	74.1	90.2	August.....	87	73	78.3	91.8
March.....	87	68	77.2	84.7	September....	91	73	79.8	86.8
April.....	87	67	78.8	85.2	October	89	72	79.5	88.8
May	91	72	79.5	89.4	November	88	71	76.8	94.3
June.....	86	73	78.9	91.0	December	84	66	76.1	94.0

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO, 1898.

Observations taken at 7 A. M., 12 M. and 7 P. M.

Day.	JANUARY.					FEBRUARY.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	81	71	76	1.5	93	76	71	73	0.0	100
2.....	71	69	70	1.5	93	74	70	72	0.5	98
3.....	70	65	68	0.5	98	74	69	71	0.0	100
4.....	70	65	69	1.0	95	75	69	72	0.5	98
5.....	76	67	72	0.5	98	75	75	71	1.5	95
6.....	77	72	75	0.5	98	81	68	74	4.0	82
7.....	78	70	75	1.5	93	79	66	74	3.5	84
8.....	82	69	76	4.0	82	74	69	72	0.5	98
9.....	79	72	76	1.5	93	81	70	74	3.5	84
10.....	....	....	....	....	....	79	70	74	2.0	91
11.....	....	....	....	....	....	81	70	76	2.5	89
12.....	86	71	78	2.5	89	80	70	75	1.5	95
13.....	82	71	76	1.0	95	80	69	75	2.5	89
14.....	83	68	77	3.5	85	78	69	74	3.5	84
15.....	74	69	72	0.5	98	82	66	75	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO, 1898.—Continued.

Day.	JANUARY.					FEBRUARY.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′	Relative humidity.
16	73	71	72	0.0	100	83	69	76	4.0	82
17	75	70	73	0.0	100	76	68	73	2.5	88
18	74	71	73	0.0	100	83	67	76	3.5	85
19	77	71	75	0.5	98	81	72	77	3.5	85
20	78	72	75	0.5	98	84	71	76	3.5	85
21	76	72	74	0.5	98	84	71	77	4.5	80
22	78	71	75	0.5	98	81	81	75	2.5	89
23	82	69	76	2.0	91	80	69	75	2.0	91
24	77	70	74	1.0	95	80	71	76	2.5	89
25	77	70	74	0.0	100	74	70	73	1.5	95
26	80	72	75	0.5	98	78	69	74	2.5	88
27	77	72	75	1.5	93	74	69	71	0.5	98
28	83	68	75	2.5	89	77	69	73	1.5	95
29	79	69	75	1.5	93	....	....	....	....	....
30	79	70	75	2.0	91	....	....	....	....	....
31	80	66	73	1.5	93	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO, 1898.

Day.	MARCH.					APRIL.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	76	71	74	2.5	88	80	72	77	2.0	91
2	84	70	77	4.0	83	84	71	78	4.5	81
3	84	68	74	3.5	84	82	72	78	3.5	85
4	82	73	77	2.5	89	82	73	78	2.0	91
5	78	73	76	1.5	93	78	74	77	0.5	98
6	80	73	77	3.0	87	80	76	78	1.5	93
7	78	72	76	1.5	93	83	75	79	2.5	89
8	83	70	76	2.5	89	84	79	82	6.5	74
9	74	70	72	0.5	98	83	71	77	3.5	85
10	82	71	77	2.5	89	86	77	81	4.5	82
11	83	72	78	4.5	81	80	79	80	3.0	87
12	83	74	78	4.0	83	85	75	80	4.0	83
13	87	75	80	5.5	77	....	....	....	....	....
14	84	71	78	4.5	81	....	....	....	....	....
15	85	70	78	4.5	81	85	68	77	5.0	78
16	85	73	78	4.5	81	87	67	77	4.5	80
17	84	75	79	4.5	81	87	75	81	4.5	82
18	85	74	79	5.5	77	86	77	81	4.5	82
19	86	69	78	5.5	77	80	76	80	3.5	85
20	85	70	78	5.5	77	80	78	81	4.5	82
21	86	72	78	4.5	81	80	76	81	4.5	82
22	84	73	78	3.5	85	77	73	75	1.5	93
23	83	72	78	3.5	85	80	74	77	1.0	95
24	79	72	77	2.0	91	84	73	80	4.0	83
25	77	74	75	1.5	93	86	73	80	4.5	82
26	83	75	79	4.0	83	75	74	75	1.0	95
27	81	72	77	2.0	91	82	72	78	3.0	87
28	84	70	78	4.5	81	84	72	79	4.5	81
29	84	73	78	5.0	79	86	73	80	5.0	79
30	82	69	75	3.5	84	83	71	78	4.0	83
31	84	75	79	3.5	85	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO, 1898.

Day.	MAY.					JUNE.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	80	74	77	1.0	95	78	76	77	0.5	98
2.....	84	72	78	2.0	91	85	75	80	3.5	85
3.....	85	72	79	3.5	85	86	81	83	5.5	78
4.....	82	76	78	1.5	93	85	80	82	3.5	86
5.....	80	75	77	0.5	98	85	82	83	4.5	82
6.....	81	75	79	1.0	96	86	80	83	3.5	86
7.....	87	79	82	3.5	86	83	77	80	2.5	89
8.....	87	76	82	4.0	84	....	....	....	....	....
9.....	86	76	82	4.5	82	....	....	....	....	....
10.....	81	75	78	1.0	96	85	79	82	3.5	86
11.....	78	75	76	0.5	98	79	75	76	0.5	98
12.....	84	75	80	2.5	90	81	75	79	2.0	91
13.....	85	75	80	3.5	85	77	76	77	0.5	98
14.....	87	74	81	4.5	82	78	73	75	2.0	91
15.....	88	77	82	4.5	82	78	75	77	0.5	98
16.....	80	74	78	1.0	96	80	78	79	1.5	94
17.....	81	74	78	1.0	96	83	77	80	1.5	94
18.....	79	76	78	1.5	93	84	77	81	3.5	86
19.....	80	75	77	1.5	93	84	75	79	3.0	87
20.....	79	76	78	2.5	89	80	77	78	2.0	91
21.....	80	74	77	1.0	95	82	76	79	2.0	91
22.....	85	76	80	3.5	85	82	77	80	2.5	89
23.....	87	78	81	3.5	86	79	76	78	1.0	96
24.....	82	76	79	1.5	94	78	75	76	0.5	98
25.....	91	77	84	5.5	78	78	75	76	1.0	96
26.....	90	76	83	5.5	78	81	77	79	1.5	94
27.....	85	78	81	3.5	86	78	75	77	1.5	93
28.....	88	79	84	4.0	84	81	76	77	1.5	93
29.....	82	76	79	2.0	91	82	73	78	2.5	89
30.....	84	77	81	3.5	86	80	75	78	2.0	91
31.....	79	75	77	0.5	98	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO, 1898.

Day.	JULY.					AUGUST.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	80	74	78	1.5	93	78	75	77	1.0	95
2.....	76	75	76	0.5	98	75	73	74	0.5	98
3.....	....	....	....	....	....	82	74	78	1.0	95
4.....	....	....	....	....	....	79	74	77	1.0	95
5.....	....	....	....	....	....	81	75	79	1.5	94
6.....	....	....	....	....	....	82	76	79	2.0	91
7.....	....	....	....	....	....	77	75	76	0.5	98
8.....	80	75	77	0.5	98	80	76	78	1.0	96
9.....	....	....	....	....	....	78	76	77	0.5	98
10.....	82	73	77	2.0	91	81	74	78	1.5	93
11.....	84	73	79	3.5	85	77	76	78	1.0	96
12.....	83	75	80	2.0	92	77	75	76	0.5	98
13.....	85	77	81	3.5	86	80	75	77	1.5	93
14.....	84	77	80	3.5	85	80	75	78	1.0	96
15.....	85	75	80	2.5	89	82	76	77	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO, 1898.—Continued.

Day.	JULY.					AUGUST.				
	Max.	Min.	Mean.	Mean t−t′	Relative humidity.	Max.	Min.	Mean.	Mean t−t.′	Relative humidity.
16.....	84	78	81	3.5	86	80	78	79	2.5	89
17.....	80	77	78	1.5	93	85	74	79	3.5	85
18.....	80	77	78	1.5	93	80	73	77	2.5	89
19.....	84	74	80	2.0	92	87	77	82	5.5	78
20.....	....	....	....	....	....	80	74	79	2.0	91
21.....	....	....	....	....	....	82	75	80	2.5	89
22.....	79	73	76	1.0	95	84	74	80	3.0	87
23.....	....	....	....	....	....	84	79	81	2.5	90
24.....	79	73	76	1.5	93	82	79	81	3.0	88
25.....	80	73	76	1.0	95	82	77	80	2.0	92
26.....	79	74	76	0.5	98	80	77	78	1.5	93
27.....	81	74	77	1.0	95	82	78	80	2.5	89
28.....	83	75	78	1.0	96	80	79	79	2.5	89
29.....	82	74	77	1.0	95	81	76	77	2.0	91
30.....	80	77	79	2.5	89	82	75	79	2.0	91
31.....	79	76	78	2.0	91	81	76	79	2.5	89

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO, 1898.

Day.	SEPTEMBER.					OCTOBER.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	83	73	78	2.0	91	87	75	82	5.0	80
2.....	82	77	80	3.0	87	84	76	80	2.5	89
3.....	76	75	76	0.5	98	81	75	78	1.5	93
4.....	....	....	....	....	....	82	74	79	2.5	89
5.....	....	....	....	....	....	81	75	79	1.5	94
6.....	....	....	....	....	....	81	73	78	2.5	89
7.....	....	....	....	....	....	85	74	80	2.5	89
8.....	77	75	76	0.5	98	86	76	81	3.5	86
9.....	81	74	78	1.5	93	86	76	79	1.5	94
10.....	82	75	79	2.0	91	87	75	81	3.0	88
11.....	83	76	80	2.5	89	86	73	81	3.0	88
12.....	84	75	80	3.0	87	85	77	81	4.5	82
13.....	84	75	78	2.5	89	80	77	78	1.5	93
14.....	80	74	79	2.5	89	77	74	75	0.5	98
15.....	82	73	77	2.5	89	79	74	76	0.5	98
16.....	89	73	81	2.0	92	82	75	79	2.5	89
17.....	87	76	80	3.0	87	89	75	82	4.0	84
18.....	87	78	82	3.5	86	88	74	79	2.5	89
19.....	79	77	78	2.5	89	89	76	83	3.5	86
20.....	81	75	79	2.0	91	88	77	84	5.5	78
21.....	85	77	81	2.5	90	87	76	82	3.5	86
22.....	84	74	79	3.5	85	87	75	81	3.5	86
23.....	87	74	80	5.0	79	82	75	79	1.5	94
24.....	88	76	81	5.5	78	80	75	78	2.0	91
25.....	83	75	80	3.5	85	74	73	74	0.0	100
26.....	86	75	81	5.0	80	79	74	76	1.5	93
27.....	86	77	82	5.0	80	83	74	79	3.0	87
28.....	89	78	83	5.5	78	84	72	80	4.0	83
29.....	91	75	83	5.5	78	89	73	83	5.5	78
30.....	90	80	85	5.5	78	86	75	79	2.0	91
31.....	....	....	....	....	....	87	75	80	3.0	87

TEMPERATURE AND RELATIVE HUMIDITY AT CAMP BARTON ON RIO DESEADO, 1898.

Day.	November.					December.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1	88	75	82.0	3.5	86	76	73	74.5	0.5	98
2	88	75	81.5	5.5	78	80	74	78.0	1.0	96
3	84	75	80.0	3.5	85	....	73	....	....	....
4	83	74	78.5	2.5	89	....	....	....	....	....
5	....	73	....	....	....	....	76	....	....	....
6	....	....	....	....	....	78	76	77.0	1.0	95
7	....	....	....	....	....	80	73	77.0	1.0	95
8	....	....	....	....	....	77	73	75.5	0.5	98
9	....	76	....	....	....	79	72	75.5	0.5	98
10	77	74	75.5	0.5	98	78	74	76.0	0.5	98
11	79	74	76.0	0.5	98	75	72	73.0	0.0	100
12	82	74	78.5	1.0	96	81	71	76.5	1.5	93
13	75	74	74.5	0.0	99	79	73	77.0	0.5	98
14	82	75	78.5	1.5	93.5	80	69	75.5	2.0	91
15	76	75	75.5	0.0	99	81	70	76.0	1.5	93
16	76	73	74.5	0.0	99	79	72	74.5	1.0	95
17	74	73	73.5	0.0	99	82	72	77.5	2.5	89
18	78	72	74.5	0.5	98	82	72	77.0	2.5	89
19	78	71	74.5	0.5	98	82	70	76.5	2.0	91
20	75	74	74.5	0.5	98	84	71	77.5	3.5	85
21	83	74	78.5	2.5	89	79	72	76.5	2.0	91
22	81	73	77.5	1.5	93	80	70	76.0	1.0	95
23	80	72	77.0	2.5	89	79	70	76.0	1.5	93
24	76	71	74.0	0.5	98	....	66	....	....	....
25	77	73	75.0	0.5	98	....	....	....	....	....
26	82	72	76.5	1.5	93	....	....	....	....	....
27	80	74	77.5	0.5	98	....	....	....	....	....
28	78	73	76.0	0.5	98	....	....	....	....	....
29	80	74	77.0	0.5	98	....	....	....	....	....
30	81	76	78.5	2.0	91	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA.

Month.	Temperature.			Mean relative humidity.	Month.	Temperature.			Mean relative humidity.
	Max.	Min.	Mean.			Max.	Min.	Mean.	
1898.					1898.				
January	86	67	77.5	82.5	September	96	72	81.2	85.0
February	84	71	77.1	81.7	October	96	72	81.4	84.8
March	90	69	78.4	80.2	November	92	72	79.7	87.7
April	89	69	79.9	79.0	December	91	72	78.3	88.0
May	94	73	80.4	82.1	1899.				
June	90	72	79.3	91.4	January	86	69	77.8	87.3
July	90	74	80.0	91.3	February	88	66	77.2	87.7
August	95	73	80.0	84.9	March	90	72	79.7	80.9

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1898.

Day.	JANUARY.					FEBRUARY.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	80	76	78	3.5	85	79	75	78	4.5	81
2	74	73	74	4.5	80	82	73	77	5.0	78
3	74	70	72	4.0	82	84	74	78	5.5	77
4	74	67	70	3.0	86	76	72	74	2.5	88
5	75	68	72	3.0	86	79	72	76	4.5	80
6	79	75	77	3.5	85	79	72	76	5.5	76
7	....	....	....	....	....	84	77	78	5.5	77
8	....	....	....	....	....	82	71	76	4.5	80
9	....	....	....	....	....	83	72	77	4.5	80
10	82	73	78	3.0	87	79	71	76	3.5	85
11	82	73	78	2.5	89	83	75	78	2.5	89
12	83	74	78	3.0	87	80	77	78	4.0	83
13	84	74	79	2.5	89	81	73	78	2.5	89
14	82	73	77	3.0	87	79	77	78	4.0	83
15	81	71	76	3.0	87	81	73	78	4.5	81
16	76	74	75	2.0	91	84	71	77	4.5	80
17	77	73	76	2.5	89	....	....	....	....	....
18	78	73	75	2.5	89	....	....	....	....	....
19	84	74	80	4.5	81	....	....	....	....	....
20	81	73	76	2.5	89	....	....	....	....	....
21	83	74	79	4.0	83	....	....	....	....	....
22	81	73	78	3.5	85	....	....	....	....	....
23	83	75	80	5.5	77	....	....	....	....	....
24	84	76	80	5.5	77	....	....	....	....	....
25	83	75	80	5.5	77	....	....	....	....	....
26	83	76	80	5.5	77	....	....	....	....	....
27	82	77	79	6.0	75	....	....	....	....	....
28	83	71	80	6.5	74	....	....	....	....	....
29	86	77	82	7.5	70	....	....	....	....	....
30	86	74	80	7.0	72	....	....	....	....	....
31	83	79	82	7.0	72	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1898.

Day.	MARCH.					APRIL.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	75	72	73	2.5	88	81	72	78	4.5	81
2	86	74	78	4.0	83	87	76	82	6.5	78
3	82	73	78	3.5	85	80	75	78	3.5	85
4	85	74	78	3.5	85	84	78	80	4.5	81
5	83	70	76	3.0	87	78	74	76	1.0	95
6	82	77	80	3.5	85	80	76	78	2.0	91
7	82	74	79	5.0	79	84	79	81	4.5	82
8	88	74	80	6.0	75	83	73	78	4.5	81
9	78	74	76	2.5	89	85	74	80	5.0	79
10	83	72	76	4.0	82	84	75	80	5.5	77
11	85	71	80	3.5	85	83	74	79	4.5	81
12	83	71	78	3.5	85	85	75	81	6.5	78
13	90	71	80	4.5	81	84	76	80	5.5	77
14	89	69	80	6.5	73	83	72	78	6.0	75
15	87	70	79	6.5	73	84	69	79	6.5	73

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1898.—Continued.

Day.	March.					April.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
16	81	71	77	4.5	80	83	70	78	6.5	73
17	85	70	81	5.5	78	83	75	80	3.5	85
18	81	72	78	5.5	77	82	77	80	4.5	81
19	84	72	77	4.5	80	88	79	84	7.5	71
20	85	75	80	7.5	81	86	73	82	6.0	76
21	84	79	81	8.0	68	85	74	80	5.5	77
22	85	71	80	5.0	79	84	72	78	4.5	81
23	83	72	78	4.5	81	86	74	80	3.5	85
24	85	71	78	6.0	75	85	80	83	6.5	78
25	85	75	78	3.5	85	89	80	84	8.0	69
26	84	79	82	6.5	74	84	75	80	5.0	79
27	86	73	80	5.5	77	87	75	81	7.0	72
28	84	72	78	6.0	75	83	72	80	6.0	75
29	83	71	76	3.5	85	83	74	80	5.5	77
30	82	69	76	5.0	78	83	71	78	5.5	77
31	83	69	81	5.5	78	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1898.

Day.	May.					June.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1	81	73	78	3.5	85	82	76	78	2.5	89
2	80	75	78	4.5	81	83	75	78	2.5	89
3	86	78	80	6.5	73	84	74	78	2.5	89
4	85	76	80	6.5	73	90	77	82	2.0	92
5	83	76	78	5.5	77	90	78	82	2.5	90
6	84	75	78	5.5	77	88	77	80	2.0	92
7	89	79	84	6.0	77	88	76	80	2.0	92
8	94	76	83	6.0	76	88	75	80	2.5	90
9	92	77	83	5.5	78	86	74	79	0.5	98
10	84	78	80	5.0	79	85	74	78	1.5	93
11	82	75	78	1.5	93	90	72	80	2.0	92
12	88	77	80	3.5	85	89	72	79	2.0	91
13	86	78	82	5.5	78	84	72	78	1.5	93
14	86	78	82	7.0	72	84	74	78	1.5	93
15	83	77	80	5.5	77	86	77	80	2.0	92
16	78	75	76	4.5	80	88	76	80	2.5	89
17	79	75	78	3.5	85	86	77	80	2.5	89
18	78	75	76	3.5	85	88	77	82	2.5	90
19	82	75	78	5.0	79	88	75	80	2.5	89
20	80	80	80	1.0	61	88	77	80	2.5	89
21	85	78	81	3.0	87	86	76	80	2.5	89
22	85	74	80	2.5	89.5	85	75	78	1.5	93
23	85	76	80	2.5	89.5	84	74	78	0.5	98
24	90	76	82	2.5	90	80	75	78	1.0	96
25	90	79	83	2.0	92	86	75	78	2.5	89
26	89	80	83	2.0	92	89	74	80	2.5	89
27	90	79	83	2.0	92	84	74	78	0.5	98
28	90	79	83	2.0	92	87	75	79	1.5	94
29	86	80	82	5.5	78	87	74	79	1.5	94
30	86	79	82	3.5	86	89	74	80	4.5	81
31	86	78	81	3.5	86	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1898.

Day.	JULY.					AUGUST.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	84	74	78	2.5	89	....	....	....	....	....
2	80	74	76	0.5	98	....	....	....	....	....
3	83	75	78	1.5	93	....	....	....	....	....
4	79	75	76	0.5	98	....	....	....	....	....
5	85	74	78	0.5	98	....	....	....	....	....
6	88	77	82	2.0	92	....	....	....	....	....
7	87	76	81	1.5	94	....	....	....	....	....
8	88	78	81	1.5	94	....	....	....	....	....
9	85	75	79	1.5	94	....	....	....	....	....
10	85	74	79	0.5	98	85	77	81	4.5	82
11	90	75	80	1.5	94	....	....	....	....	....
12	90	75	80	1.5	94	77	75	76	1.5	93
13	....	....	....	....	....	....	....	....	....	....
14	89	74	82	4.5	82	....	....	....	....	....
15	....	....	....	....	....	....	....	....	....	....
16	90	77	84	4.5	82	86	73	80	3.0	87
17	82	76	80	3.0	87	....	....	....	....	....
18	86	82	84	4.0	84	....	....	....	....	....
19	84	78	82	5.5	82	....	....	....	....	....
20	....	....	....	....	....	....	....	....	....	....
21	....	....	....	....	....	....	....	....	....	....
22	....	....	....	....	....	87	73	80	3.5	85
23	....	....	....	....	....	95	78	82	5.5	78
24	....	....	....	....	....	86	73	81	4.5	82
25	....	....	....	....	....	....	....	....	....	....
26	....	....	....	....	....	82	77	80	3.5	85
27	....	....	....	....	....	84	74	80	3.0	87
28	....	....	....	....	....	....	....	....	....	....
29	....	....	....	....	....	....	....	....	....	....
30	....	....	....	....	....	....	....	....	....	....
31	....	....	....	....	....	....	....	....	....	....

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1898.

Day.	SEPTEMBER.					OCTOBER.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1	....	....	....	....	....	90	76	83	4.5	82
2	84	72	80	3.5	85	92	74	83	4.5	82
3	80	75	77	2.0	91	82	72	75	2.5	89
4	....	....	....	....	....	86	72	79	3.5	85
5	83	73	80	3.5	85	83	74	80	3.0	87
6	84	....	....	....	....	83	74	79	2.5	89
7	82	75	79	2.5	89	90	76	82	3.5	86
8	79	74	76	1.5	93	84	77	80	2.5	89
9	84	73	79	3.0	87	92	74	83	5.0	80
10	83	72	79	3.5	85	94	72	83	6.5	74
11	....	....	....	....	....	91	74	81	4.5	82
12	....	....	....	....	...	90	72	81	4.0	84
13	....	....	....	....	....	82	72	78	3.0	87
14	....	....	....	....	....	80	74	76	2.0	91
15	91	80	84	4.5	82	80	74	77	2.0	91

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1898.—Continued.

Day.	September.					October.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
16	....	....	....	....	....	85	74	80	3.0	87
17	....	....	....	....	....	86	75	81	3.5	86
18	....	....	....	....	....	89	74	81	2.5	90
19	79	76	78	1.5	93	90	74	82	4.5	82
20	81	74	78	1.5	93	91	76	83	5.0	80
21	88	74	81	3.5	86	91	76	83	4.0	84
22	89	74	81	2.5	90	96	76	85	4.5	82
23	93	72	82	5.0	80	84	80	82	3.5	86
24	92	73	85	7.0	73	85	74	80	3.5	85
25	89	76	82	2.5	90	90	73	82	3.5	86
26	85	76	80	2.5	89	85	74	80	4.5	81
27	84	75	80	3.5	85	90	73	82	3 5	86
28	91	80	86	5.5	79	90	83	86	3.5	86
29	96	83	88	7.5	72	92	84	88	4.5	83
30	95	84	88	7.5	72	85	76	81	2.5	90
31	....	....	....	....	....	95	74	86	6.0	77

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1898.

Day.	November.					December.				
	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.	Max.	Min.	Mean.	Mean t—t′.	Relative humidity.
1	92	76	83.5	4.5	82	80	72	76.5	2.0	91
2	89	74	83.0	4.5	82	86	75	81.0	2.5	90
3	84	79	81.0	5.5	78	85	77	80.5	2.0	92
4	91	74	82.5	7.0	72.5	91	77	84.0	4.5	82
5	87	76	81.0	3.5	86	79	77	78.0	2.5	89
6	77	74	76.0	2.0	91	82	76	79.5	1.5	94
7	78	74	76.5	2.0	91	85	73	79.5	3.5	85
8	78	73	76.0	3.5	85	85	75	78 5	2.5	89
9	89	76	84.0	4.5	82	82	72	76.0	3.5	85
10	83	73	77.5	3.5	85	83	75	78.0	2.5	89
11	86	76	80.5	4.5	81.5	76	73	74.5	1.5	93
12	88	74	82.5	3.0	88	84	72	77.5	2.5	89
13	78	74	76.0	1.5	93	85	74	77.5	2.5	89
14	87	76	83.0	2.5	90	85	74	77.5	3.0	87
15	78	76	77.0	1.5	93	85	72	76.5	3.0	87
16	78	75	76.5	1.5	93	83	74	77.5	2.5	89
17	78	72	75.5	0.5	98	83	74	77.0	2.5	89
18	78	75	76.5	1.5	93	85	74	78.0	4.0	83
19	86	76	81.5	2.5	90	85	74	77.5	3.5	85
20	82	75	77.5	3.0	87	85	74	78.5	3.5	85
21	84	72	79.5	3.5	85	87	76	80.5	3.5	85.5
22	85	76	81.0	3.5	86	87	74	80.5	5.5	77.5
23	83	76	79.5	2.5	89	84	75	79.0	2.5	89
24	84	76	81.0	0.5	98	86	70	78.0	1.0	96
25	82	74	78.5	2.0	91	85	73	79.0	5.5	77
26	86	76	79.5	3.5	85	....	74	....	....	....
27	85	76	80.5	2.0	92	....	....	....	....	....
28	87	76	82.5	3.5	86	....	....	....	....	....
29	85	76	81.0	3.5	86	80.0	77	78.5	2.0	91
30	86	76	80.0	2.0	92	80.0	72	76.0	1.5	93
31	....	....	....	....	...	82.0	74	77.5	2.0	91

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1899.

Day.	JANUARY.					FEBRUARY.				
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	79	77	75.0	3.5	84	82	79	79.5	4.5	81
2.....	86	78	81.0	4.5	82	84	72	78.0	3.5	85
3.....	83	76	79.0	3.0	87	83	73	78.0	3.5	85
4.....	84	74	79.0	2.5	89	81	73	76.0	2.5	89
5.....	83	74	77.5	2.0	91	83	72	77.0	3.0	87
6.....	82	73	77.5	2.0	91	84	72	76.5	1.5	93
7.....	83	73	76.5	2.5	89	87	72	77.5	3.0	87
8.....	85	71	77.5	2.5	89	88	72	78.5	2.5	89
9.....	84	73	78.5	3.5	85	84	74	77.5	3.0	87
10.....	83	72	77.5	2.0	91	81	73	75.5	3.0	87
11.....	85	73	78.5	2.5	89	86	74	80.0	3.0	87
12.....	82	74	78.5	3.0	87	84	72	79.5	1.5	94
13.....	82	75	78.5	3.5	85	76	74	75.0	3.5	84
14.....	83	73	77.0	2.0	91	71	66	69.0	1.5	93
15.....	83	75	79.0	4.0	83	77	70	73.5	1.5	95
16.....	80	74	77.5	2.0	91	82	70	76.0	2.0	91
17.....	81	73	76.5	2.5	89	86	72	80.5	3.5	85
18.....	81	73	77.5	2.5	89	84	72	78.0	3.0	87
19.....	79	76	77.5	3.5	85	84	74	78.0	3.0	87
20.....	82	73	77.5	2.5	89	85	73	78.5	3.5	85
21.....	85	73	78.5	3.0	87	82	75	79.0	2.5	89
22.....	84	71	77.5	3.5	85	84	77	80.0	2.5	89
23.....	82	72	77.5	3.5	85	84	79	81.0	4.5	82
24.....	80	74	77.5	2.5	89	81	74	77.0	2.0	91
25.....	83	73	77.5	3.5	85	82	76	78.5	3.5	85
26.....	81	72	77.5	3.0	87	....	....	....	....	....
27.....	83	71	77.0	3.5	85	83	74	78.5	2.0	91
28.....	84	69	76.5	3.5	85	84	77	79.5	3.5	85
29.....	....	....	....	....	....	....	....	....	....	....
30.....	84	71	77.5	3.5	85	....	....	....	....	....
31.....	85	72	78.5	2.5	89	....	....	....	....	...

TEMPERATURE AND RELATIVE HUMIDITY AT GREYTOWN, NICARAGUA, 1899.

Day.	MARCH.					Day.					
	Max.	Min.	Mean.	Mean t−t′.	Relative humidity.		Max.	Min.	Mean.	Mean t−t′.	Relative humidity.
1.....	81	75	77.5	3.0	87	17.....	80	72	76.5	2.5	89
2.....	83	75	79.0	3.5	85	18.....	86	73	78.0	4.0	83
3.....	82	74	77.5	3.0	87	19.....	86	75	80.0	4.0	83
4.....	84	74	78.5	4.0	83	20.....	89	77	81.5	5.0	79
5.....	84	73	79.0	4.5	81	21.....	87	77	81.0	5.5	78
6.....	89	78	80.5	5.0	80	22.....	90	75	81.0	4.5	82
7.....	78	73	76.0	3.5	85	23.....	86	77	80.5	6.0	76
8.....	84	77	79.5	6.0	75	24.....	86	75	79.5	4.5	81
9.....	84	76	79.0	4.5	81	25.....	89	76	81.5	6.5	74
10.....	86	78	81.5	7.5	70	26.....	86	76	80.5	5.0	79
11.....	87	72	79.0	5.5	77	27	88	75	81.0	5.5	78
12.....	85	74	79.0	2.5	89	28.....	83	75	79.0	3.5	85
13.....	86	75	79.5	4.5	81	29.....	86	76	80.5	3.5	86
14.....	82	75	78.5	3.0	87	30.....	88	78	82.0	6.5	74
15.....	86	76	80.5	5.0	80	31.....	87	78	81.5	6.0	76
16.....	88	76	81.5	6.0	76						

APPENDIX IV

REPORT

ON THE

WESTERN DIVISION

BY

J. W. G. WALKER
Assistant Engineer

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APPENDIX IV

WASHINGTON, D. C., April 20, 1899.

MR. E. S. WHEELER,

Chief Engineer, Nicaragua Canal Commission, Washington, D. C.

Sir:—In compliance with the instructions contained in your letter of February 21 I have the honor to submit the following report of my entire operations connected with the Nicaragua Canal Commission, including all matters which seem to me of interest or of value to the Commission.

I was appointed an Assistant Engineer by the Commission on the 6th day of August, 1897, and entered at once upon the discharge of my duties. These duties were varied in character and included the compilation of information likely to prove useful in our subsequent investigations, as well as the ordering and inspection of various articles of equipment necessary for the proper prosecution of work in the field.

On the 5th of December I sailed from New York for Greytown on the gunboat "Newport," with the members of the Commission and the engineering staff. Landing at Greytown on the 18th instant I immediately proceeded to the Nicaragua Canal Construction Company's buildings at La Fé, where a temporary camp was established under the direction of Lieutenant Hanus, U. S. Navy.

On the 21st of December I received instructions to take charge of Topographical Party No. 1, and to make all necessary surveys between Lake Nicaragua and the Pacific ocean. Nine assistants from the engineering staff were assigned to me and I was directed to equip my party and proceed as soon as possible to my destination. By working on Christmas day and Sunday, I was able to take the steamer "Hollenbeck" from Greytown on Monday morning, December 27, and at about 3 o'clock Tuesday afternoon we reached Castillo and passed the custom house, but remained aboard the "Hollenbeck" for the night.

Wednesday morning was spent in transferring our freight and ourselves to the steamer "Vero," which lay above the rapids, and at one o'clock we left for San Carlos, reaching there about nine o'clock in the evening. Here we transferred to the lake steamer "Victoria," which was lying at the dock awaiting the arrival of another river boat before sailing for San Jorge. The next day was spent at San Carlos, but late in the afternoon of the 31st, we sailed for San Jorge, the port of Rivas.

Reaching San Jorge early New Year's morning, I proceeded at once to Rivas and arranged to quarter my party at the house of Mrs. Runnels, while I was hiring laborers, breaking out freight, and arranging to put my party into the field. As it was a "feast day" it was almost impossible to accomplish anything, but I finally succeeded in hiring four carretas, or native ox

carts, and hauling our freight to Rivas. I also engaged Nicanor Ortega, an intelligent native, who has been on many surveys, and directed him to employ twenty laborers, telling him that I should hold him responsible for their efficiency and good behavior.

The next day being Sunday my party remained in Rivas, but in the afternoon I rode out to the mouth of the Rio Las Lajas with Mr. F. H. Davis, an American resident, to obtain an idea of the character of the country in which the first part of our work would lie.

Monday morning, the 3rd of January, we loaded most of our possessions upon carretas and moved out to San Pablo, on the bank of the Rio Las Lajas about one and a sixth miles from Lake Nicaragua. The remainder of the day was spent in erecting our tents and getting the camp into shape.

From this time on the work was prosecuted with great vigor. It had been my intention to re-run the line adopted by the Canal Company as their final location, putting in the adjacent topography with comparatively little instrumental work, but I soon became convinced that owing to the character of the country and the denseness of the vegetation, topography so obtained would be very unreliable while the strip of country covered would be too narrow to embrace all locations which the Commission might desire to study. I therefore sought and obtained your permission to change my plan of action and to make a detailed survey from Lake Nicaragua to the Pacific ocean of a belt of country containing all practicable locations. In order to perform this work rapidly and economically I increased the size of my party, taking Mr. F. H. Davis as an additional transitman and Messrs. Fred. Davis and A. L. Scott as assistants. This enabled me to run four instruments—two transits and two levels—and to accomplish twice as much work per month without a corresponding increase in expenses. I decided to run a main line following as nearly as practicable the Canal Company's low-level location, cross sectioning or running such side lines as would best give us the desired topographical information. These topographical lines were in general so arranged as to form a series of traverses with the main line, thus enabling us to immediately detect any considerable inaccuracy and to correct it before proceeding with our work.

By the 5th of February our main line had reached the telegraph road from Rivas to San Juan del Sur, about three and two-thirds miles from the lake, and we moved camp to Espinal, on the summit of the Continental Divide.

During this period of our work we were much annoyed and delayed by the frequent impressment of our laborers for military service. Nicaragua was suffering from one of the civil wars so frequent in her history and although we were freely furnished with *boletas*, or safe conducts, for our men, there were few instances in which they were respected by sub-officials of the government which issued them. Laborers in camp or actually at work in the field were never molested, but messengers or stragglers were often seized and imprisoned despite the boletas which they carried. A personal appeal to the authorities always resulted in the release of such employees, but the time and energy expended in protecting our men might have been utilized elsewhere to advantage. My American assistants were never interfered with and although I was twice seized by bands of armed insurgents, I was courteously treated and released upon establishing my identity.

My chief difficulty was in obtaining supplies, since the government had seized the "Victoria"

and communication with the east coast was interrupted. In this connection I wish to express my indebtedness to Dr. S. M. Cole, an American resident of Rivas, whose kindness in advancing funds enabled me to tide over a critical period in my party's affairs.

On February 26, our survey having reached a point about six and four-tenths miles from the lake, we moved camp to a place called Paraiso, in the upper part of the gorge of the Rio Grande. Here the country is very rough, quite different from the gently rolling territory which our center line had passed through heretofore, but as only one location for the canal is practicable, we were spared the necessity of extending our survey as far laterally as we had previously done.

On March 23rd we moved our camp from Paraiso to El Pavon, at the entrance to the Tola basin, and by the end of the month our survey had reached a point about eight and four-tenths miles from the lake. During the last half mile of this distance a great deal of work was done south of the main line in order to include a possible railway location above the 110-foot contour.

On the 23rd of April we moved camp to a spot south of the Rio Grande just below the site of the proposed La Flor dam, and by the end of the month our work was completed to a point ten and six-tenths miles from the lake. With the exception of the meander of the 110-foot contour on the north side of the Tola basin, the belt of country available for canal construction had been surveyed and platted and an examination made for a railway location above the 110-foot contour on the south side of the Tola basin.

On the 1st of May, as the rainy season was approaching, and our tents afforded shelter insufficient for the whole party, I was constrained to reduce my force materially and to finish the survey with only two instruments.

Our last work in connection with the main line at Brito was finished on the 27th of June, but a sudden rise in the Rio Grande prevented us from crossing it until the 30th, when we moved camp to a point on the Rio Tola about one and a fifth miles from the town of Tola. The entire meander of the 110-foot contour on the north side of the Tola basin and of the Rio Tola and tributary streams was done from this camp, which was centrally located. This work was finished on the 9th of August.

On the 10th of August we moved our camp to a place on the Rio Grande five hundred feet above the point where our main line first crossed it and near the hacienda called El Carmen. From this camp we meandered the upper Rio Grande, Cascabel creek, and Cañas Gordas creek, and ran various lines for topography. We also ran a line up Guarumo creek and down Comalcaqua creek to its junction with the Rio Juan Davila, putting in enough of the adjacent topography to enable us to locate and compute a channel to divert the upper Rio Grande eastward into Lake Nicaragua should it be thought advisable. This work was finished the 20th of September, and on the 22nd we moved to Rivas, stored our camp equipment and disbanded the party.

I returned to the United States by way of Panama, accompanied by Messrs. E. B. Harden, and M. A. Coroalles, the other members of the party having assumed the duties to which you had previously assigned them.

Canal Belt.

What may be termed the canal belt between Lake Nicaragua and the Pacific ocean begins on the lake at the mouth of the Rio Las Lajas. A

tangent from the initial point with a magnetic bearing of about south sixty-one degrees west forms the longitudinal axis of this zone, traverses a gently rolling, partially wooded valley, crosses the river four times, and leaving it six thousand eight hundred feet from the lake, follows the valley of Guiscoyol creek to a point 12,900 feet beyond. Here the axis of the zone curves gently to the right, crosses the summit of the Continental Divide at an elevation of 154 feet above the sea and a distance of five miles from Lake Nicaragua and dropping gently down, enters the valley of the Rio Grande. Following the river in a northwesterly direction and crossing and recrossing it repeatedly, it runs for nearly two miles through a rough country between precipitous hills where outcrops of partially disintegrated rock are everywhere visible. Emerging from this rocky gorge with a westerly bearing, it almost immediately curves to the northward through the plain at the mouth of Guachipilin creek, and, still following the general direction of the Rio Grande with a bearing of about north fifty-four degrees west, runs through a gravelly and somewhat rock valley between high hills 1000 to 1500 feet apart to the Tola basin, which it enters at a distance of about ten and a half miles from the lake.

The Tola basin is a broad, alluvial plain, very level and heavily timbered, and but for the problem of handling the flood waters of the Rio Grande and Rio Tola, the location of a canal would be a very simple problem, two points being determined by its entrance into the basin and by the gap in the La Flor hills through which it must make its exit in a southwesterly direction. Beyond these hills is a broad, alluvial plain bounded by widely separated ranges of hills and gradually sloping down to the beach at Brito, three miles away.

Nearly the entire canal belt is heavily timbered, the only considerable open tract being in the big bend of the Rio Grande below La Flor.

The harbor possibilities at Brito are limited by the precipitous rocky headland known as Brito Head and by a rocky hill some 7000 feet to the southeastward. These two eminences are the termini of the ranges of hills bounding the valley, which in its lower portion is a silted estuary extensively inundated at high tide and overgrown with a tangled mangrove forest.

The beach, which extends from the southeastern hill to the mouth of the Rio Grande, is of white sand quite different from the material brought down by the river, and this, with the fact that the shore line seems to have remained unchanged for many years, may be accepted as proof that a littoral current whose action is limited by the adjacent rocky headlands, operates to prevent the further encroachment of sedimentary deposits and to maintain the beach and neighboring sea bottom as they exist at present.

The prevailing winds are off-shore, the waves are of moderate height and no indications of destructive storms from the sea were observed.

The rock in the adjacent hills is badly disintegrated and it is not probable that much material suitable for breakwaters could be obtained from them.

Rio Las Lajas.

The lower portion of the Rio Las Lajas, which lies in the canal belt, is in the dry season a quiet lagoon ranging from 60 to 150 feet in width and with an average depth of about 12½ feet. In some places it has cut a channel in the soft rock to a considerable depth, but during most of its length it seems to flow through earth. It is said that during the rainy season it becomes a large stream with a swift current, but I never

had an opportunity of observing it at such a time and the rapidly growing, rank vegetation upon its banks speedily obliterates all signs of high water.

Rio Grande.

The Rio Grande is formed by the junction of the Rio Cascabel and Cañas Gordas creek about nine-tenths of a mile southwest of the point where our line first crosses it. These tributary streams rise some miles southwest and south, respectively, of their junction, and drain a considerable tract of country. Frequent outcrops of rock are visible in the banks of the Rio Grande from its origin to the Tola basin and again at La Flor, although the bed of the stream is usually gravelly, and the fact that these outcrops occur on the outsides of bends seems to indicate that the present river is meandering between rocky barriers which in former times bounded a much larger stream. This old river bed has been traced by Dr. C. W. Hayes, the Geologist of the Commission, from the upper end of the gorge of the Rio Grande to a point about three-quarters of a mile above the entrance to the Tola basin. It varies from 120 to 220 feet in breadth and is in general about three times the width of the present river. Whether it once carried the waters of Lake Nicaragua to the Pacific, as has been suggested, must, with the information now at our command, remain a matter of conjecture, but it is a plausible, if not a conclusive, explanation.

During the dry season the upper Rio Grande practically ceases to exist, the water seeping from pool to pool through intervening bars of gravel, but when the rains begin it is subject to sudden and great floods, eroding its banks and carrying large quantities of material thus excavated to the sea. Some of the tributary streams, notably Guachipilin creek and the Rio Tola, discharge water during the entire dry season, and it is probable that below the mouth of the latter the Rio Grande never ceases to flow.

Method of Conducting Surveys.

As has already been stated, the method adopted was to run a main line following substantially the Canal Company's low level location and to attach to this such lines as were necessary for an accurate determination of the surrounding topography. These auxiliary lines wherever practicable, were so disposed as to form a series of traverses with the main line, thus enabling us to compute the degree of accuracy with which our work was performed and to avoid carrying forward any appreciable error. In general, no transit work, except that in river beds, was considered satisfactory in which the error exceeded one in one thousand and in most cases it was well within this limit. Thus the curve through the gorge of the Rio Grande, the roughest territory which we encountered, was tied by a chord joining its extremities, forming a traverse 16,442 feet in length in which the error was about five feet, or one in 3288; while a traverse 17,030 feet in length which formed part of the north Tola basin meander closed within two feet. The compass was used to some extent on short and unimportant auxiliary lines, but nearly all the work was done with transits, the calculated courses being carried forward from the lake and the needle being used merely as a check.

Obstacles to Survey.

The chief obstacles to the survey during the dry season, setting aside those of a political nature already touched upon, were the denseness of the vegetation, the comparative inefficiency

of native labor, the prevalence of "pica-pica," a plant bearing a pod which sheds a dry, irritating dust almost unendurable, and the extraordinary number of wasps' nests encountered.

During the wet season the heavy rains and consequent condition of the country rendered progress slow and laborious.

Result of Survey.

The result of our survey has been the production of a map which is believed to be very accurate, and from which, in connection with the reports of the Commission's geologist and hydrographer, all data necessary for an intelligent comparison of alternate routes may be obtained.

Personnel.

I give below a statement of the assistants employed upon this work, together with the dates upon which they joined and left my party.

Name.	Occupation.	Joined.	Left.
E. B. Harden,	Assistant Engineer,	Dec. 21, 1897;	Sept. 22, 1898.
M. A. Coroalles,	Instrumentman,	Dec. 21, 1897;	Sept. 22, 1898.
F. H. Davis,	Instrumentman,	Jan. 27, 1898;	Apr. 30, 1898.
J. D. Forster,	Instrumentman,	Dec. 21, 1897;	Feb. 12, 1898.
H. C. Hurd,	Instrumentman,	Dec. 21, 1897;	Sept. 21, 1898.
C. P. E. Peugnet,	Instrumentman,	Dec. 21, 1897;	May 14, 1898.
P. H. Belknap,	Assistant,	Dec. 21, 1897;	Apr. 8, 1898.
J. A. Bull,	Assistant,	Dec. 21, 1897;	Jan. 21, 1898.
Fred. Davis,	Assistant,	Feb. 12, 1898;	Sept. 17, 1898.
E. P. Humphrey,	Assistant,	Mch. 2, 1898;	May 14, 1898.
L. R. Lee,	Assistant,	Dec. 21, 1897;	July 23, 1898.
O. B. Powell,	Assistant,	Dec. 21, 1897;	June 14, 1898.
A. L. Scott,	Assistant,	Feb. 17, 1898;	Apr. 30, 1898.

Distance Run.

The total amount of line run was 304.6 miles, which may be divided as follows:

	Miles.
Main Line	17.489
Cross sections	100.115
Rio Grande meander	21.512
Cañas Gordas meander	.977
Rio Grande and Cañas Gordas offsets	13.907
North Tola basin meander	14.370
Lines for topography	36.864
South Tola basin meander	5.315
Lines for topography	8.254
Rio Grande diversion meander	5.116
Lines for topography	24.387
Random lines for topography	56.295
Total	304.601

Alternate Routes.

Four routes between Lake Nicaragua and Brito have been proposed and their relative defects and advantages will be briefly discussed in the following paragraphs.

Hydrographic Considerations.

In order to make intelligent comparison of these alternate routes an understanding of the functions to be performed by the canal is essential. The chief of these is, of course, the retention in a state of comparative repose, of a body of water sufficiently deep and broad to permit the passage of shipping, and as every canal is to

a certain extent a drain, its usefulness for purposes of navigation depends upon the amount of water which passes into or through it and upon the possibility of regulating the height and velocity of this water within certain well-defined limits. A knowledge of the fluctuations of the lake level and of the steps which must be taken to regulate it is therefore indispensable, and it is in this kind of information that the Maritime Canal Company seems to have been deficient.

Mr. A. P. Davis, the Commission's hydrographer, reports that in order to control the lake within a five-foot limit—that is, between elevations of 105 and 110 feet above the level of the Caribbean sea, or 106 and 111 feet above the level of the Pacific ocean—a spillway having a capacity of 50,000 cubic feet per second for 183 days out of the year should be provided. As the distance from the present outlet of the lake to the highest location which has been suggested for regulating works on the Rio San Juan is considerable and as the channel of the river is tortuous, it seems desirable to drain a large part of the superfluous lake water through the Western Divide into the Pacific ocean. No low pass in the divide at a reasonable distance from the lake is available for a separate waste-way and we are therefore constrained to so increase the area of the cross section of our summit level cut as to permit its use both as canal and waste-way. The Commission's location is such that one channel will serve both purposes, the water not needed for the canal being discharged through regulating works situated at a distance of 9.8 miles from the lake.

Rio Medio Route.

This route follows the valley of the Rio Medio from the lake, crosses the divide at an elevation of about 243 feet above the sea, enters the valley of the Rio Grande near the mouth of Guachipilin creek and passes through the Tola basin and La Flor hills to Brito. This route may be dismissed as involving very heavy excavation without accomplishing its object of avoiding the Rio Grande, which, if used as a waste-way, would be so augmented by the drainage of the lake as to make impracticable the project of conducting both it and the canal in separate channels through the valley between Guachipilin creek and the Tola basin.

Canal Company's Low-Level Route.

The second route, known as the Canal Company's Low-level Location, leaves the lake 900 feet north of the mouth of the Rio Las Lajas and runs south 61° west up the valley of this stream, which it crosses four times within 6800 feet. Beyond the last crossing it continues in the same direction up the valley of Guiscoyol creek to a point 19,700 feet from the lake, where it curves gently northward, crosses the Continental Divide at an elevation of 154 feet above the sea and at a distance of five miles from the lake and enters the valley of the Rio Grande. It follows this stream through its gorge, curving first northward and then westward, and emerging with a westerly bearing upon a small plain at the mouth of Guachipilin creek, sweeps northward again to the first lock site about 2500 feet beyond the creek crossing. From this point the line follows the right bank of the Rio Grande to Brito, cutting off an occasional bend and terminating near Brito Head. Four locks were contemplated, the first, already referred to, having a descent of 25 feet; the second and third, situated in the upper part of the Tola basin 10.8 miles from the lake, and at La Flor 14.4 miles from the lake, respectively, having a fall of 30 feet each; and the fourth, about 6000 feet from

the beach at Brito, having a fall of 25 feet at mean tide or 29½ feet at low tide. The total distance from the lake to the beach at Brito is about 17.4 miles and the maximum curve has a radius of 4297 feet.

The inadequacy of the works proposed by the Canal Company is apparent upon examination. The cross section of their summit level cutting is so small as to make its effective use as a waste-way impracticable, while the fact that the level of the lake, even with ample regulating facilities, will at certain times not exceed 106 feet above the sea, would reduce the minimum depth of water in this portion of the canal to 26 feet. Even with suitable modifications of design this route is open to some objections, the chief ones being the unnecessary length of line and the impossibility of avoiding taking the flood waters of the Rio Tola into the canal below the regulating works.

Canal Company's High-Level Location.

The third route, known as the Canal Company's High-Level Location, is identical with the preceding to a point 8.4 miles from the lake and near the crossing of Guachipilin creek. Here the two lines separate, the one now under consideration following the general course of the river and entering the Tola basin, which is to be made a part of the summit level by means of a dam closing the gap in the hills at La Flor through which the Rio Grande now flows. This dam must have a length of 2000 feet on the crest and must rise to a height exceeding 111 feet above the sea, 71 feet above the general plain of the valley, and 88 feet above the bed of the Rio Grande at this point. Recent borings by the Commission show that a suitable foundation may be obtained at an elevation of 40 feet below sea level; hence the height of a dam at this point, from foundation to crest, would exceed 151 feet. The Canal Company proposes to place a weir in the saddle of an adjacent hill and by this means to discharge the drainage of the valley and about 60 per cent. of the surplus discharge of the lake watershed. Two locks of 42½ feet fall each, are to be placed in the rocky spur southwest of the western end of the dam and 14.36 miles from the lake, and from this point the line continues in a tangent to Brito, passing through the lock site 6000 feet from the beach mentioned in the description of the Canal Company's Low-Level Line, and which in this line is also the site of a proposed lock with a fall of 25 feet at mean tide or 29½ feet at low tide. The total distance from the lake to the beach at Brito by this route is 17.4 miles and the maximum curve has a radius of 4297 feet.

The advantages claimed for this plan are the addition of 4.6 miles of free navigation to the summit level, the saving of canal excavation for this distance, the formation of an inland harbor 4000 acres in extent, and the satisfactory disposition of the drainage of the Rio Tola. The fact that the adoption of a high-level line would permit the waste of lake water through a channel at a greater distance from the canal at La Flor than would otherwise be practicable, is also worthy of consideration.

The disadvantages are the magnitude of the dam, the depth of foundations, the difficulty of disposing of the drainage of the valley during construction, the possibility of the failure of the structure, with all its attendant evils, the excessive fall of the locks, and the unnecessary length of line.

The works proposed by the Canal Company are unsuitable for the conditions which we now know to exist, for reasons given in the discussion of their low-level route.

Nicaragua Canal Commission's Location.

The fourth route, which is recommended by this Commission, is identical with the two preceding locations from the initial point to the place where they diverge, 8.4 miles from the lake. Here the Commission's line curves to the northward, follows the left side of the valley of the Rio Grande, enters the Tola basin at the base of the hills which bound it on the south, curves around these hills to the left and, traversing a part of the alluvial plain which indents the high land to the south, crosses a spur of the La Flor hills to the left of the Rio Grande and emerges from the basin. Fifteen hundred feet beyond it curves to the left, crosses the river twice, sweeps to the right at the base of one of the range of hills bounding the valley on the southeast and runs to the beach in a direction approximately parallel to the lines already discussed.

It is proposed to construct a low-level canal along this location, the summit level being of such dimensions as shall allow of its use both as waste-way and canal. At a point 9.8 miles from the lake regulating works would be constructed and the surplus water discharged into a channel north of the canal. This channel would be excavated artificially, but it is thought that the water, which would be under control, might be relied upon to enlarge it from a small cutting to the required size. The bed of the Rio Grande is to be utilized wherever practicable. The first lock would be situated just below the regulating works and 10.2 miles from the lake, the location of the others depending upon the number decided upon.

The chief advantages of this route for a low-level canal are its length, which is 16.9 miles, or one-half mile less than either of the Canal Company's locations, its avoidance of the flood waters of the Tola, which would enter the waste-way to the north of the proposed canal, and the great number of good natural lock sites over which it passes. The maximum curve has a radius of 4297 feet.

Our recently acquired hydrographic information demonstrates the impracticability of diverting the upper Rio Grande as proposed by the Canal Company, and the reception of its flood waters into the summit level of the canal is contemplated.

General.

The following general observations and suggestions are submitted as having a more or less direct bearing upon the problem of canal construction.

Labor.—The labor supply upon the western division is insufficient and unsuitable for the prosecution of an engineering work of magnitude. The natives are indolent, although probably not more so than other inhabitants of the tropics, and are unaccustomed to and unfitted for arduous labor. If well treated and protected from arbitrary arrest and conscription, they would be available in limited numbers for comparatively light work, but the greater part of the labor supply must be obtained elsewhere.

Health.—The health of my party was, upon the whole, excellent and I believe the climate to be a good one. The most prevalent diseases are malarial fevers, which are common among the lower classes during the rainy season, but which need not be greatly feared by those able and willing to take care of themselves. I am inclined to think that dissipation, due to a lack of the resources and restraints of home, is accountable for much of the fever from which strangers suffer.

Food Supply.—Although the present food

supply is only sufficient to sustain the present population, an increased demand would probably result in an adequate supply of corn, beans, and plantains. Other foods, with the exception of beef, which is plentiful but poor, would have to be imported.

Water Supply.—The only considerable quantities of good water between Lake Nicaragua and the Pacific ocean, which are available during the dry season, come from Guachipilin creek, Chocolata creek and the Rio Tola. Throughout most of the canal line some system of water works would have to be established.

Fuel.—Wood is abundant and may be had for the cutting. Coal would have to be imported.

Land.—As far as I have been able to determine, two hundred pesos per cavalleria is a fair average price for unimproved land bought in large tracts. Assuming exchange at 2.50 that would be seventy-one and four-tenths cents per acre. Cleared or cultivated land is, of course, worth much more.

Assuming that strips of land 1200 feet wide are required for canal and waste-way respectively, the quantities appropriated for the works, exclusive of Brito harbor, would be approximately as follows:

Nicaragua Canal Commission's line, 3350 acres; Nicaragua Canal Co.'s high-level line, 5985 acres; Nicaragua Canal Co.'s low-level line, 3280 acres.

It is assumed that the whole Rio Grande valley below the lower end of the Commission's proposed tide lock would be needed for Brito harbor. Its area is approximately 661 acres and the land is at present valueless.

Hubs.—Hubs and bench marks in future surveys should be made of imperishable material and buried slightly beneath the surface of the ground to guard against their destruction by the extensive fires which rage during every dry season. If wood is used it should be carefully selected, as most varieties rot rapidly in that climate.

Roads.—The best roads are but rough tracks in the dry season and are practically impassable except for horsemen during the rains. They might readily be improved, however, as semi-disintegrated rock is plentiful and easily handled.

Police System.—An efficient police force, quite independent of the local authorities, should be established at the beginning of construction and should rigorously enforce order and a compliance with sanitary regulations. The sale of liquor on or near the work should be prohibited.

Postal System.—A postal service should be maintained for the use of those engaged upon the work, and in no case should the mail bags leave the hands of responsible American employees.

Monopolies.—It is the policy of the Nicaraguan Government to increase its revenues by selling or leasing to corporations, firms, or individuals, the exclusive right to pursue certain profitable industries. Thus the steam navigation of the Rio San Juan and Lake Nicaragua is monopolized by one company, a percentage on the price of beef killed for sale in the department of Rivas must be paid to the owner of a concession, and all freight landed at San Juan del Sur must pass over a wharf whose owner is legally protected from the annoyances of competition.

The existence of this system should be borne in mind and a definite understanding should be reached with the Government and with the holders of such concessions by which obstructing

rights shall be waived or reasonable charges guaranteed.

Earthquakes.—At about half-past ten on the morning of April 29, 1898, while we were encamped at La Flor, there was an earthquake of considerable violence but of brief duration. I at once examined several steep-cut river banks in the neighborhood but they apparently had suffered no change. No harm was done at Rivas, although in Granada and Managua some walls were slightly cracked. The canal belt seems to lie in a favored region where such disturbances are never serious.

Conclusion.

Upon the completion of my field work I returned to the United States and reported for duty at the Washington office on the 27th of last October. Since that time I have been employed upon general office work and in the preparation of estimates of which you have been furnished copies.

In conclusion I wish to express my appreciation of the services rendered by the members of my field party, and especially by Mr. E. B. Harden, who was attached to my party at his own request, and to whose skill and unflagging energy is due much of the excellence of the map.

Very respectfully,

J. W. G. Walker,
Civil Engineer, U. S. N.,
Assistant Engineer.

APPENDIX V

REPORT

ON

SAN JUAN RIVER AND LAKE NICARAGUA

BY

FRANCIS LEE STUART
Assistant Engineer

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APPENDIX V

WASHINGTON, D. C., April 15, 1899.

MR. E. S. WHEELER,

Chief Engineer to Nicaragua Canal Commission, Washington, D. C.

Sir:—December the 17th, 1897, upon arriving in Greytown I was put in charge of one of the Precise Level parties. After breaking out an outfit and adjusting instruments, etc., I was directed to proceed to San Carlos and take charge of the survey of the San Juan river.

Upon completion of this survey I was instructed to make a triangulation and hydrographic survey of Lake Nicaragua.

I have the honor to submit the following reports:

TOPOGRAPHIC AND HYDROGRAPHIC SURVEY OF THE SAN JUAN RIVER FROM LAKE NICARAGUA TO THE CARIBBEAN SEA.

SCOPE OF SURVEY.—In January we measured a base line 15,044 feet long near San Carlos for the use of the hydrographic party then making a survey of that portion of Lake Nicaragua which lies between the Solentiname islands and San Carlos where the lake discharges into the San Juan river.

On January the 29th, 1898, we began the survey of the San Juan river using station A of the hydrographic base line located at the southwest corner of San Carlos Morro as the zero of survey, and the top of inshore end of old boiler in Lake Nicaragua, elevation 109.75, for the basis of our levels.

We carried the stadia line, the line of levels, and the topography of the banks as far as Punta Gorda, Lieut. G. C. Hanus, U. S. N., in charge of the naval party, making the hydrographic survey of this portion.

From Punta Gorda, Lieut. Hanus and party having been recalled to the United States for other duties, we took up his work as well and carried the entire survey to the San Francisco river. At the San Francisco river, jumping around twelve miles previously surveyed by this Commission, we took up the survey again at the Los Cuellos islands and completed the survey of the San Juan to a point 12½ miles from Greytown, where we connected with the survey of Assistant Engineer Andrew Onderdonk.

From the junction of the San Juan and Colorado rivers we also completed a survey down the Colorado river to the sea, including a survey of the Caño Bravo.

From the Parado creek on the San Juan we also ran a direct line to the nearest point on the sea.

A special investigation was made at Machuca for a dam site.

GENERAL CHARACTERISTICS OF THE RIVER.

The San Juan is formed by the discharge of the Lake Nicaragua watershed and finds its way

to the Caribbean sea through the lower third of the Nicaraguan depression or valley, which begins at the headwaters of the Sinicapa river in the northwestern end of Nicaragua and runs southeasterly to the sea at Greytown. The San Juan valley is narrow, with water-parting lines considerably closer to the river on the north side than on the south.

The river bottom presents four distinct and peculiar features:

1st. From the outlet of the lake to the trap-rocks of Castillo it is at present flowing in an opposite direction from its old course, which was to the Pacific through an older channel that has been partially silted up.

2d. From Castillo to Machuca it flows over a rocky bed which does not show evidence of an older channel, its present cut through the old divide having been made since the lake began to flow into the Caribbean sea.

3d. From Machuca to the mouth of the San Carlos river it flows in an old river bed not yet silted up. That this old bed is at or below sea level is a striking evidence that a subsidence of the region has taken place.

4th. From the mouth of the San Carlos river to the sea the old bed continues sinking deeper, but a great quantity of volcanic sand from the Costa Rican mountains has been deposited by the San Carlos river, filling up the old channel and forming an entirely new and much flatter gradient for the present river bed.

Details.—From San Carlos to the Savalos river at the head of the Toro rapids, a distance of 27.16 miles, the river falls 5.4 feet, the banks are flat with low open marshes extending back a considerable distance on both sides of the river. These marshes are covered with water except at a very low stage of the river.

The banks of the river below the water surface are steep, seem to hold well, are regular, and of about a uniform depth. The hills rise very abruptly upon the confines of the marshes and except for a stretch of half a mile at Melchora there is no ground which gently slopes to the river level, a slope of more than 5° being the dominant characteristic of this section. At Martinez, San Francisco, Palo de Arco, and Savalos ranches, the cattle feed in the marsh during the dry season, in from $1\frac{1}{2}$ to $2\frac{1}{2}$ feet of water. One thousand acres covers about all the land so used which came under our observation.

Forest trees are sparse, the vegetation of the swamps being chiefly palms, bushes and vines. There are seven hills which are close to the river, but none give evidence of serviceable rock for building purposes, except a ridge of mountains which rises from the swamps within a mile of the river at Isla Grande. This ridge also has some timber on it.

In this section the old bed of the river may have been anywhere in this valley, the present conditions giving evidence that the old topography has been drowned, except the hills, and that the present bed of the river and the level ground, such as marshes and swamps, has been made by the river in comparatively recent times.

From the Savalos river to the foot of the Toro rapids the river falls 7.3 feet in 1.7 miles between a series of hills on the south bank, and one hill and low ground on the north.

From the foot of the Toro to the beginning of the Castillo rapids the river falls 1.2 feet in 7.98 miles. The valley gradually narrows until it is some 3000 feet wide between the hills at the rapids. This section has the same characteristics as the section above the Toro, except that there are no open marshes but swamps. At Castillo the river falls 6 feet in 2000 feet, over apparent boulders and rocks.

The village of Castillo consists of about 50 frame and cane houses, these being between six and eight feet above the river on the one street of the town. The principal are the two frame warehouses belonging to the C. & P. Transit Co., one eight feet above the water and the other four.

The Nicaraguan Government frame warehouse is six feet above the water, and a custom house about eight feet. The custom house also contains barracks for soldiers, which are always kept at this point, an old fort on the hill above the town being still in service.

The rapids at this point are so shallow that all freight brought by river steamers, except during very high water, is transported on a tramroad, which runs through the only street of the town, and connects the two warehouses of the Transit Company.

From the bottom of Castillo rapids to Punta Gorda the river falls 2.5 feet in 2.08 miles. In this distance there are three small houses on the river bank.

From Punta Gorda to a mile below Machuca rapids, a distance of 10.62 miles, the river falls 26 feet over a succession of short rapids, the Mica, Balas, Patricia, Infernito and Machuca. The valley is narrow and well-defined, the hills on either side forming the banks, the bottom of the river being chiefly rock. But two clearings or houses are visible from the river.

From a point one mile below Machuca to the mouth of the San Carlos river, a distance of 14.79 miles, the river falls 1.0 feet. This section is called Agua Muerta (dead water) and is the best defined river bed on the San Juan. The hills on both banks make a narrow, well-defined valley and exclude the idea that the river could ever have been in any other position in this section than where it is now. The river is narrow and from 18 to 50 feet deep with rock bottom at points. The banks are well wooded and there is rock suitable for small rubble work in some of the surrounding hills. There is but little swamp land, and that only in small pockets.

From the mouth of the San Carlos to the San Juanillo river, a distance of 33.02 miles, the fall is 30 feet. The character of the river changes, and the bottom is entirely shifting sand to a considerable depth. The banks are of alluvial material, and there is other evidence of a drowned topography. The hills in this section are of no great height, generally from a hundred to two hundred feet above sea level. There are scattering clearings and houses along this section, the principal being at the mouth of the San Carlos, Palo Seco and Remolinita.

At the San Juanillo we enter the coastal or delta plain which spreads fan-shaped to the sea. The north confines of this plain are the San Juanillo and Juan rivers, and to the south the Colorado river. The general slope of this plain to the sea is about one foot and a half to the mile, and is at a height of about extreme high water of the rivers which meander through it. It is dotted here and there with islands, lagoons and partially drowned hills. The forest consists of Silico and other palms with a few scattering hard-wood trees.

The distance from the San Juanillo to the junction of the San Juan and Colorado rivers is 5.28 miles, and the fall 4 feet. From this junction to the sea, via the San Juan, the distance is 18.65 miles and the fall 21 feet. From this junction via the San Juan to Parada creek and thence in a straight line across the swamps and lagoons to the sea, the distance is 12.03 miles. From the junction to the sea, via the Colorado river alone, the distance is 23.7 miles, and via the Colorado river and Caño Bravo the distance

is 19.7 miles. This part of the coastal plain, through which the Colorado and Bravo flow, is almost entirely composed of islands and lagoons up to the foot of the Costa Rica hills, which rise to the south side of this river and which are the only hills visible in this section. There are scattering forest trees on the Costa Rica hills and some rock suitable for rock-filling work. There are but two houses between the junction and Colorado bar.

In the above description distances are measured along axis of river, and for heights the lake was taken at 104 and the sea zero.

The Bends of the San Juan River.

There are on the river a number of bends, by cutting across which the canal route may be considerably shortened. Eight or ten of these are low ground and show no evidence of rock; two others, however, at the mouth of the San Carlos river and in the Agua Muerta are of high rocky land and will have to be cut through or skirted by curves of the minimum radius.

Machuca Dam Site.

An investigation was made at Machuca for a dam site. On the north bank a crest at an elevation above 110 was closed for two and a half miles and a reconnaissance made until the Machuca creek itself was above 110. On the south bank a crest was closed for one and a half miles, when the general characteristics of the country indicated that there was no possibility of any embankment being needed, the ridge itself being well defined, and as far as we went nothing was found below an elevation of 160 on the crest. Topography was also taken for a lock site.

The Tributaries of the San Juan.

The San Juan has a number of small tributaries and but few large ones, the most important being the Frio, Poco Sol, San Carlos and Sarapiqui rivers, all of which rise in the Costa Rica mountains on the south side of the valley. From the lake to Castillo, among the tributaries to the north, are the Melchora, Palo de Arco, Negro, Savalos and Santa Cruz rivers. From the south are the Frio, Medio Queso, Poco Sol, and Poquito Sol rivers. These, as far as I have observed, all seem to flow in a northwesterly and southwesterly direction until they join the main river. The Rio Frio in times of high water is also a tributary of the lake.

Among the tributaries from Castillo to the sea, Bartola, Machuca, N. Cruz, Machada, Danta and San Francisco are from the north, and the Infernito, S. Cruz, San Carlos, Cerano, Tamborcito, Copalchi and Sarapiqui rivers are from the south. These all seem to rise normal to the San Juan.

On entering the delta plain the distributaries of the San Juan are the San Juanillo, San Juan (proper), Colorado, Taura, Parada and Caño Bravo, the rivers discharging into the sea at Harbor Head, Colorado bar, Greytown and the mouth of the Taura. At times the openings at Greytown and the mouth of the Taura are closed.

The tributaries of the whole river are seldom, if ever, muddy or carrying sediment. In fact the San Juan and its tributaries may be said to be remarkably free from sediment in the ordinary acceptance of the term. The San Carlos, however, discharges a very considerable quantity of volcanic sand, as does also the Sarapiqui, though to a lesser degree. The rest of the rivers, so far as observed, are free from this sand.

Fluctuation.—From the nature of the upper San Juan from the lake to San Carlos river, it is of slow movement as to rise and fall; two-thirds of its water coming from the lake, which serves as an equalizing basin.

In the reach above the Toro the greatest difference of height between low and full river corresponds to the varying height of the lake, and from the Toro to the Agua Muerta it has a probable fluctuation of eight feet. From its constant nature this part of the river can be dealt with with a degree of confidence not usual.

The lower portion of the river from the mouth of the San Carlos to the sea presents a combination of conditions quite different. Its tributaries, at times of exceptional flood, are torrential and have a combined discharge twice as large as the upper San Juan for a few hours. The San Carlos at times backs up the San Juan in the Agua Muerta and presents an exceptional case of a tributary depositing sand for some distance upstream against the current of the main river. There is a probable fluctuation at periods of extreme low and high water of some 15 or 20 feet. From conclusions arrived at from various sources, I estimate there may be a fluctuation of from 4 to 8 feet in 24 hours in this portion of the river.

Winds.—The northeast trade winds predominate in the San Juan valley but do not reach a velocity sufficient to be considered in any way detrimental in the canal question.

Rocks.—The rocks found along the river consist generally of dolorite, or diabase having a badly decomposed surface, and volcanic breccia. Nearly everywhere, except in the bottoms of the ravines, the rock is covered with a heavy layer of clay.

None of the rock which we have seen has appeared suitable for cut work. Much of it, however, is suitable for filling in, notably at Toro rapids, Castillo, Punta Gorda, Machuca, Agua Muerta, San Francisco and Loma Ultima on the Colorado river about six miles from the sea. On the west side of the lake there is a species of basalt which is used in the masonry work of the country. This, however, from what I am able to learn, cannot be easily obtained in thickness of over a foot.

Timber.

Trees Suitable for Piles in the Sea.—Pejebaya, Makenga, Cocoanut—the old trees of these varieties may be found scattering in the coastal plain, and it is believed that they will withstand the attacks of the Toredo Navalis better than any other untreated indigenous wood.

Trees Suitable for Exposure to Weather, Earth or Fresh Water.—Palo Cortez, Guachipilin, Roble-Montez, Cocobole, Granadillo, Guyacan, Almendro, Pine, Madera Negra and Guapinole. The first seven are very hard woods and can be found straight up to 25 feet. The pine grows in quantity along the coast from Pearl lagoon up to Honduras. In Pearl lagoon there are at present saw mills with capacity of 10,000 feet B. M. per day. The Madera Negra grows very crooked, but is the best wood in the country for cross-ties.

Wood Used in Buildings.—Cedro, Pochote, Nispero, and Laurel. With the exception of pine the before mentioned woods do not grow in groups, and in the forest on the east side can only be found in small clusters of from two to ten. As most of these woods sink in rafting, and on account of the expense of getting such scattering trees to a mill, I am of the opinion that the native timber cannot be depended upon for canal construction, and that such timber as is necessary can be imported considerably cheaper than by establishing mills. All timber not imported which is used along the river or in the interior is sawed by hand, there being no mills around Lake Nicaragua.

Present Land Values and Fertility.—There is no attempt at the cultivation of crops

in the San Juan valley. There are two ranches which are making a desultory attempt to plant rubber and cocoa trees. The cattle are few and very poor. Banana cultivation is prohibited by a lack of harbor facilities.

From the density of the vegetation the land is very fertile. This fertility being the great drawback of the region with its present facilities, the forest vegetation is with great difficulty subdued and at too great a cost. Considering the location, present condition of river and seaport, the climate and rainfall, I deem this valley about as valuable as our western deserts, and that it will take as much energy and industry to develop it as it has to transform these western wastes with which we are familiar.

Rainfall.—The rainfall at Greytown is about 250 inches per year, while sixty miles north or south of Greytown it is very much less. The rainfall also diminishes on ascending the river to the lake where there is a distinct wet and dry season.

The excessive rainfall at Greytown may be caused by the moisture-laden trade winds being disturbed by the effects of the Nicaraguan depression on their currents, thus inducing precipitation as they strike the coast at Greytown, which is normal to the wind; but a satisfactory cause for this peculiarity of the region has never been given.

Climate.—The climate on the San Juan river has been very uniform, rarely very hot or cold, and I would conclude from the fact that the eight or ten officers and the thirty or forty laborers who have composed our camp for the last seven months have all been in good health (with one exception), that the river at present is very healthful. The men, ourselves included, have camped in tents along the banks of the river, have been exposed to the constant rains, have had no water to drink except that of the river, have followed the dictates of their tastes in eating such food as was provided, have had no medical attention, and yet have been perfectly well.

The river is very sparsely settled, but of the population who lead temperate lives we have seen little or no sickness. That this general healthfulness of the river valley will continue under the construction of the canal is unlikely, and provision will have to be made for handling the sick.

Labor.—The labor of Nicaragua is adapted to such classes of work as machete work, clearing right of way, or packing in supplies to camps by canoe or trail. This is about the extent to which the native labor may be depended upon in any quantities. The great drawbacks in teaching them other work are that they are not accustomed to work more than half the day, are not prompt, have known little but martial restraint, and are restless and constantly on the move. Not knowing the incentive of hunger, and having no ambition, they cannot be depended upon for the mainstay of the construction of the canal. Such labor will have to be imported at the beginning of work and such forces added to, year by year, until completion.

Imported labor deteriorates rapidly. My opinion being expressed in percentage of a man's usefulness in the United States, is, for the first 12 months, 75 per cent., second 12 months, 50 per cent., and by that time he has assimilated so much of the habits of the tropics that his usefulness in some branches of work is entirely gone.

Political Division.—From the sea to a point three miles below Castillo the San Juan river forms the boundary line between Nicaragua and Costa Rica. Circling with Castillo as a center, and with a three-mile radius the boundary line

swings to the south of the river and keeping three miles distant runs parallel to the river and lake to the Sapoa river, which empties into the lake opposite Madera. From the Sapoa river the boundary line strikes across to the Pacific ocean at Salinas bay.

Deduction as to Canal Field.—From the information enumerated in this report, I am of the opinion that the use of the San Juan from a point half a mile above the mouth of the San Carlos river to the junction of the San Juan and Colorado rivers is prohibited for canal purposes, as is also the south side of the river between these two points. This leaves the upper San Juan and the north bank of the lower San Juan as the field for a canal, and one which does not necessitate the solving of other than very simple engineering problems, and with few, if any, unknown conditions to be guessed at.

Remarks.

Value of Survey.—In conclusion, I wish to add that the survey of the river (proper) is ample for preliminary locations of a canal. Special studies will have to be made in more detail of the various bends and dam sites as is usual before final location.

The soundings of the river appear to be ample for final locations, necessitating only the ordinary cross sectioning before construction begins.

Suggestions.—It seems to me pertinent to make the following suggestions of work that it might be advisable to do prior to the acceptance of any location as final, and pending the commencement of such detail work of investigation as properly comes under the head of constructive locations:

The development of the 110-foot contour in the upper reaches of the river;

Further detail topography of the delta plain;

Additional sectional borings of the river could with advantage be taken at San Carlos, Melchora, Savalos, Castillo, and one mile above Machuca;

A more extended topographic study of the region to the eastward of the southern portion of the lake; or it might also be well to make a barometric reconnaissance for forty miles north of Castillo for the purpose of ascertaining definitely that the increase in the height of the valleys and summits to the northward is a fact, as is pointed out by all deductions on the subject, a recorded instrumental proof being alone lacking.

As there seems to be disagreement of the various determinations of the latitude and longitude of Greytown, San Carlos and Brito, and as there is a telegraph with cable connection at these points, this matter could and should be readily settled.

Methods of the Survey.—The general method by which the work of the survey was done was to establish a camp of tents and native sheds on the banks of the river, finish the work for four or five miles on either side of the camp and then move to the next camp site in our small canoes, provisions being sent once a month from Greytown on the river steamers.

The Stadia Line.—The stations on this were placed at an average distance of about 1200 feet apart. Depending on the nature of the ground four kinds of stations were used; first, the ordinary hub, where the ground was sufficiently firm; second, three small piles for the tripod where the ground was unstable; third, a large pile to which the trivet was nailed; fourth, the prepared stump of a tree to which the trivet was also nailed; in the two latter cases the observer stood in a boat, as the station was usually in from two to six feet of water.

In observing, the back and front transit rods

were read for azimuth, and then the stadia rods for thread readings as nearly simultaneously as possible, all three threads being read and the vertical angle noted, if any. The forward and back readings between stations were averaged for the true distance between any two stations.

The Levels.—After reading for distance and azimuth the instrument was adjusted for the level readings and the front and back rods read as nearly simultaneously as possible, the two upper hairs being read and this reading compared with the stadia reading. The elevation of the surface of the water was also taken at each station as an additional check. The elevation of the instrument above the top of all the hubs occupied was taken. This gave two determinations of the elevation of each station, the notes being so divided as to keep two sets of levels, and the average was used as the true elevation.

The shore line was taken with the stadia, the up and down river boats approaching each other until they met, points being taken about every 300 feet.

Topography.—Topography was taken by cutting trails into the woods from 600 to 1000 feet in length and about 1000 feet apart, on both banks, compass, chain and hand-level being used. The taking of the topography was particularly difficult, owing to the denseness of the vegetation.

Sounding.—Sounding sheets were prepared from the stadia notes and on them the sounding lines laid out 540 feet apart, as being a multiple of 27. In determining the position of the sounding lines the center of the river was generally used as an axis and radii of 3000 feet or more used when curves were necessary.

In the field flags were placed on the sounding lines as located on the sheets, and then these lines sounded, one observer being in the boat to take straddling angles, while a laborer occupied the opposing flag and kept the boat on line, the lead being thrown every 20 seconds. From Machuca to the Rio San Francisco a center line was also run, two observers being in the boat.

The atmospheric conditions are excellent and for the seven months that we were in the field we worked in all conditions of weather, losing but one entire day on account of a heavy downpour of 12 hours. While working in the almost incessant rains of this region our instruments were kept under large umbrellas and only a heavy downpour obscuring sight delayed the work.

Members of Party.—The party on the survey of the San Juan was composed of the following members: Francis Lee Stuart, chief of party; S. S. Evans and Thaddeus Merriman, observers; C. H. Stockton, topographer; C. L. Hammond, draughtsman; and Messrs. Bernstein, Torrington and Williams, rodmen; and from 20 to 40 native laborers.

The checks that we have been able to obtain on our work were of such a creditable nature that I deem them worthy of mention.

On a line of levels, S. S. Evans observing, the stations being from 1000 to 1500 feet apart, and the length of line 69 miles, the Precise Level party afterwards checked our work within 1/10 foot for 56 miles, and within 3/10 foot in 69 miles.

I append herewith a description of the method of leveling which we used on our survey, prepared by S. S. Evans, assistant engineer, at my request.

In our stadia work, Thaddeus Merriman observing, on a circle of 20 miles, with stations from 1500 to 2000 feet apart, the geodetic positions checked within 80 feet, and the levels on the same line by less than 1/10 foot.

I wish to express my appreciation of the services of my assistants which were well and cheerfully performed.

LAKE NICARAGUA.

The survey of the San Juan was finished September 1, 1898, and proceeding to San Carlos, with a newly organized party, we made a triangulation and hydrographic survey of Lake Nicaragua.

Scope of Survey.—The entire lake has been surveyed and sounded out.

The zero of the survey of the San Juan river from San Carlos to the sea has been connected with the zero of the survey of west side from the lake to the Pacific, thus making a continuous survey from ocean to ocean.

The initial point of lake survey being station A of hydrographic base line at San Carlos, a skeleton system of triangulation was developed and then the shore line and islands and soundings filled in. A second base line was measured at San Jorge for the purpose of a check on the accuracy of the work.

Soundings were taken in a systematic way over sailing routes of canal and also over the entire lake. Diligent search was made for sunken peaks or bars.

Location.—Lake Nicaragua is an oblong body of fresh water 101.2 miles long by 45.1 miles wide as extreme dimensions, with an area of 2975 square miles. Its greatest length is in a northwesterly or southeasterly direction, it being a part of the long narrow basin which runs northwesterly across Nicaragua from Greytown to the headwaters of the Sinecapa river.

It belongs to the Atlantic watershed at present, the line of water partings of the two oceans forming the southwesterly boundary of the lake basin.

This parting line in the stretch of country separating the lake from the Pacific is but five miles from the lake, the lake shore itself approaching within twelve miles of the ocean.

The discharge of the lake has its outlet at San Carlos in the southeast end, and flows through the San Juan river a distance of 121.7 miles into the Caribbean sea. The lake surface was from 104 to 106 feet above Caribbean mean sea level during this survey.

The highest point of the canal route through the Continental Divide is but 50 feet higher than the surface of the lake. This point is in the lowest depression in the dividing chain of hills between the oceans that has been found on the continent.

Bottom.—The bottom of the lake is covered with silt and has for the most part a gentle slope towards Ometepe and Madera.

The greatest depth found was 200 feet, about three-quarters of a mile southeast of Madera.

There is a well-defined depression that has been only partially filled up in the general leveling that has taken place. This depression or channel is found at two points and is parallel to the axis of the lake, one portion north of the Solentiname groups of islands, and the other and deeper portion near Madera. This is an unmistakable evidence of a drowned topography.

A sand bar was found on a line between Ometepe and Punta Palmar, which extends a couple of miles into the lake.

With these two exceptions the bottom of the lake was found to have been quite uniformly leveled by the silt.

In general, the 30-foot curve is about half a mile from the shore on the south and west sides, from one to two miles on the north side and from ten to fifteen miles in the southeast end near its outlet. Of the 2975 square miles of the lake's

area, 2300 square miles has a depth of over 30 feet.

Watershed.—The watershed of 12,500 square miles, including the lake itself, may be said to be elliptical, its width being 70 miles and length 250 miles, its greatest length being parallel to the axis of the lake.

The boundary lines of this watershed can be described as, on the south and west the Costa Rican and Nicaraguan mountains, lying in that narrow stretch of country which separates the lake from the Pacific; on the north and east by dissected plateaus under the general name of Chontales hills.

This shed is subject to a wet and dry season of about equal duration. The rainfall varies, however, in different parts of the watershed, being generally greater in the San Carlos end than in the Managua. This is due to the northeast trade winds arriving laden with moisture collected in their passage over the ocean. This moisture begins to be precipitated on reaching the east coast of Nicaragua and continues, though constantly diminishing, to San Carlos, thus causing a less marked wet and dry season there than on any other portion of the watershed.

The superficial strata of the basin is permeable and covered with heavy turf and vegetation, and consequently the amount of detritus brought down into the lake is small in comparison with similar basins in the temperate zone which have a smaller rainfall that is more uniformly divided during the year.

Fluctuations.—The area and capacity of the lake is so large in proportion to its watershed that it necessarily varies but slowly from any possible set of the physical conditions by which it is governed. Its fluctuation from any possible combinations of conditions in 24 hours may be from 6 to 12 inches.

The fluctuation from any consecutive wet and dry season is from 3 to 8 feet.

The extreme fluctuation reported from any series of wet years for highest water, and any series of dry years for lowest water, is believed to be 13 or 15 feet.

Principal Tributaries.—On the north side the Malacatolla, Apala, Ormiguerro, Mollales, Nancital, Catarina, Ollate, Tepenaguasape and Camastra rivers;

On the southeast, the Frio, Poponochal, Papanuro and Zapote rivers;

On the south the San Bartolo, Pisote, Sapoa, and Ochomogo rivers, and on the northwest the Tipitapa river which connects Lake Nicaragua with Lake Managua.

During the wet season the rivers have considerable currents while in the dry season nearly all become stagnant and their mouths fill up with a long grass, which, breaking loose at the beginning of the wet season, floats around the lake, finally disappearing down the San Juan river.

But two or three of the tributaries have any flow in the dry season, the Rio Frio in the southeast end, and the Tipitapa in the northwest end have the most noticeable flow and even these are said to be stagnant at times.

From its tributaries and basins during the six months of wet season, the lake receives enough water in excess of evaporation and discharge to give it a storage capacity to withstand the action of evaporation and discharge during the dry season within limits of 3 to 8 feet.

Islands.—The principal islands in the lake are the island of Ometepe and Madera, containing 107 square miles, formed by two extinct volcanoes; the island of Zapatera, containing 21 square miles, and the Solentiname group of islands, containing 14½ square miles. There

are also quite a number of small islands in the lake, but with the exception of Isla Sonate all are within a few miles of shore. These islands are of varying heights; from an elevation of 5110 feet, which is the height of Ometepe, to 20 feet above the lake at Sonatito. Most of these islands appear in the lake without any fixed relation to the topography of the shore.

A diligent search by us, extending over several months, has not developed any sunken peaks.

Shore.—The shore line may be divided into four well-marked divisions, showing the influence of the trade and west winds.

First, from Punta Boquete to Las Haciendas the shore is almost entirely a swamp, having a mat of long grass back of which the tree line is well marked. This is seldom a lee shore. The hills back of the swamp or marsh rise abruptly and partake of the general topography of that section of the San Juan valley between the Toro rapids and San Carlos. There is but one town (San Carlos), which is situated on a hill. In all, some ten houses in this section would be damaged by an elevation of 115 feet for surface of lake. The marsh land is at times used for pasturage, but to no considerable extent.

Second, from Las Haciendas to the Rio Tipitapa is a lee shore for ten months out of the year, which has a sandy beach with occasional rocky spurs east of San Jorge. The settlements on this shore are Las Haciendas, 15 houses, situated on a sandy bar with an elevation of 112 feet; Sabalos also on a sandy tract with an elevation of 117 feet; and Port of Granada, with five buildings, below 115 feet. There are also some isolated houses on this section which are about 115 feet.

Third, from Rio Tipitapa to San Ubaldo is very seldom lee shore and is mostly a swampy shore with grass; the only firm ground of any magnitude close to the shore is in the vicinity of Pelona and Congrejo. There are probably some five or six farms at an elevation of 110 feet in this section.

Fourth, from San Ubaldo to Punta Boquete is a lee shore for two months of the year. The shore is firm, mostly rock, except the sandy beach at San Ubaldo, Morito and San Miguelito. The two latter are small villages on hillsides of gradual slope. This shore is wooded, but not heavily, and hills rise frequently from the water's edge. Some 10 houses are at an elevation of 112 feet in this section.

The island of "Ometepe and Madera" has firm shores and there may be some half dozen houses at an elevation of 112 feet on the islands.

The other islands of the lake have usually rocky shores and there are not more than six houses at an elevation of less than 112 feet.

It may be well to add that the term house in this respect applies to a building of from one to two rooms, made without the use of any manufactured articles such as match boards or tiles, and without a floor, except earth; usually made in Nicaragua out of canes, and with a thatch roof, and of little value.

Winds.—Winds on the lake vary with the wet and dry seasons but the northeast winds predominate.

From November or December to April or June is the dry season and the winds blow from the northeast to east. The rest of the year is called the wet season and the winds are variable at times. They blow occasionally seven or eight days from the west, when the northeast winds return. During July, August, and September there are frequent short squalls.

There are seldom, if ever, heavy storms on the lake, though strong squalls develop at times.

The lake is well protected from northers by the range of high mountains to the north.

The trade winds crossing the lake are strong and steady and similar in character to those met in the Caribbean sea off the Greytown coast, and, like Greytown, the lake is outside of the range of the cyclonic disturbances of the West Indies.

Waves.—The waves from the trade winds are short and choppy and, while it is believed that they do not exceed 8 feet from crest to trough on the southwest shore where they are the heaviest, they should not be disregarded. A small breakwater at the entrance to the canal at Las Lajas being advisable. The San Carlos end is protected by hills and will not need such a provision.

Anchorages.—To the west side of Madera, San Francisco bay, carrying 40 feet of water, offers a particularly good anchorage for ships. It is opposite the entrance to the west side canal. The bay is 2½ miles by 5 miles, and the deep water approaches close to the shore.

At Moyogalpa on the west side of Ometepe is a shallow indentation, with a sandy beach free from rocks offering a safe anchorage for ships.

Sailing Route of Canal.—The distance along sailing route of canal through the lake from San Carlos to the lake entrance of the west side canal is 71.2 miles, of which 13.1 miles at the east end will have to be dredged, the rest of the distance carrying ample water for the heaviest ships.

Land Values.—From observations I am of the opinion that but small damage to property around the lake will be caused by the surface of the water reaching at times an elevation of 112 feet. Land along the shore at an elevation between 110 and 120 is used principally for cattle pasturage. There are no cultivated areas, but scattering here and there may be found cursory and unmethodical attempts to raise the necessary food for the immediate families.

Climate.—The climate on the lake is different from that of the San Juan river and under present conditions can be said to be healthful except during the months of change from the wet to the dry seasons.

Labor.—More extended observation on the labor question in Nicaragua but confirms my previous impressions, that any work of magnitude which is to be pushed will have to rely on imported labor and will cost more than similar work in the United States.

Method of Survey.—A skeleton triangulation was developed in which all stations were occupied, except Ometepe, in which case the angles were deduced. Natural signals were cut in from the stations. The shore line was located by actual occupation of shore points and also cut in from inshore sounding lines. Soundings were taken from the Nicaraguan Government steamer "El 93," which was placed at the disposal of the Commission for these studies. Sounding platform was four feet above water and the lead used 12 pounds. A sounding was taken every minute or half minute, and in water over 7 fathoms, speed was slackened every five minutes for check soundings. Sounding positions were taken every five or ten minutes by sextant observers in the steamer.

Members of Party.—The party consisted of Francis Lee Stuart, chief of party; Thaddeus Merriman, C. H. Stockton, C. L. Hammond, George J. Smart, R .N. Begien, J. C. Taylor, R. C. Wheeler, Sherwood Wilson, and Lester Bernstein, and from 40 to 70 native laborers.

We commenced the survey September 1, and that we were able to finish November 21, 1898,

was due to the efficiency and zeal of my assistants.

After completion of the lake survey the steamer "El 93" was returned to the Nicaraguan Government and I disbanded my party, leaving three members for further duty in Nicaragua and directing the others to report in Washington.

WORK IN THE UNITED STATES.

Upon arrival in the States the following maps were made of the survey of Lake Nicaragua: Smooth map of Lake Nicaragua to a scale of $\frac{1}{100000}$ showing triangulation stations, signals, sounding positions, soundings and shore topography. Record map for reconstruction, 8 miles to the inch, showing triangulation stations, signals and cuts, with angles, distances, etc. Map of Lake Nicaragua, scale $\frac{1}{120000}$ for publication.

I was also assigned to make estimates and studies of lock and dam systems and possible canal variants on the eastern division, and Mr. Thaddeus Merriman, R. N. Begien and R. C. Wheeler reported to me as assistants.

Summit Level.

In considering any question relative to the summit level of the canal such as width, depth, slope of canal section or dams and controlling works, the subject of control of the lake is most important, and should be studied first under certain assumptions and a decision made.

The limit of range of fluctuation of the lake to be provided for has been fixed by the Commission at 6 feet or from a surface elevation of 104 to 110 feet.

It has been assumed that the current in the basin from the lake to the San Carlos river must not be so great as to cause erosion of banks, thus necessitating constant cleaning out of channel.

Storage Capacity.

Briefly the conditions which affect the storage capacity of the lake during the year of minimum inflow and maximum evaporation, are:

During a dry season the evaporation may exceed the inflow by 6 inches per month.

The maximum evaporation for a dry season may be 60 inches.

The minimum inflow may be 36 inches, thus leaving the lake 24 inches lower than at the beginning of the cycle.

Considering that the following dry season may give an additional fall of 23 inches and that the operating of the locks and electric plants may cause a drop of 4½ more in 18 months, we have 51½ inches as a necessary range for storage capacity should the lake not receive any inflow except as at present. If, however, the water from the San Juan basin be impounded during this period it is believed that the 51½ inches would be reduced to 42 inches.

With its present inflow the lake may be governed in a year of maximum inflow and minimum evaporation with constant discharges for 164 days as follows:

Within limits of 5-ft. rise by a discharge of 33,300 cubic feet per second.

Within limits of 4-ft. rise by a discharge of 39,200 cubic feet per second.

Within limits of 3-ft. rise by a discharge of 45,100 cubic feet per second.

Within limits of 2-ft. rise by a discharge of 51,000 cubic feet per second.

Within limits of 1-ft. rise by a discharge of 56,900 cubic feet per second.

Within limits of 0-ft. rise by a discharge of 62,500 cubic feet per second.

However, the question is not the control of the lake alone but of the lake and so much of the San Juan river as may be used for canal purposes.

The time covered by observations that have been made as to rainfall, evaporation and run-off is not extensive enough to warrant any assumption on the subject being other than good approximations. In view of this fact Mr. Davis's statement that the San Juan river may receive from its tributaries between the lake and the San Carlos river, 50,000 cubic feet per second, coupled with the knowledge that the rainfall in the San Juan valley is many times heavier than on the lake, must be interpreted. The extreme assumption that can be made is that the 50,000 cubic feet or a large portion of it is discharged into the San Juan for a number of days or weeks during the wet season.

If we assume that the 50,000 cubic feet is delivered to the river in a uniform way, as from zero at the lake and being augmented proportionally to the distance until the sum of the increments is equal to 50,000 cubic feet at Boca San Carlos, and fix a limit of velocity in the channel of 2 feet per second on account of the quality of material and the sloping sides below the surface, the canal section being 300 feet wide on bottom with side slopes 2 : 1; then an inspection of the table of velocities will show that with one dam in river, the east spillway can take care of the heaviest rainfall in the San Juan valley and also, if desirable, of 10,000 cubic feet in addition from the lake, without causing a velocity greater than the limit except at the cut-off at Sombrero de Quero.

The requirements, then, for governing the summit level, which seem advisable until further information is at hand, are:

That there be a spillway on the west side and that it have a capacity of at least 30,000 cubic feet per second.

The spillway at dam on east side should have a capacity of 60,000 cubic feet per second or more.

The controlling works at spillway on east side should be able to hold the water at 114.

The lock walls should be built to 116.

If we had no information of value about the lake, with desirable limits of fluctuation between 104 and 110, it would be proper at all times to endeavor to keep the lake as near 107 as possible. We do know, however, that it is an extremely unusual year which does not have a very marked wet and dry season in this region. This fact is of prime importance in dealing with this problem and we can presume on it to the extent of operating the east and west side plants with a view to having the elevation of the lake at 108 at the beginning of any dry season and at the beginning of the wet season 106½ or as much lower as it may be from losses by evaporation and operating alone.

From the beginning of any wet season until the lake reaches 108 there should be no waste allowed, but upon reaching that point the spillways should be used to their full capacity until the lake ceases to rise.

Though it is feasible it cannot be considered desirable to have as much of a current on the east side as is given by a discharge of 10,000 cubic feet per second in addition to the 50,000 cubic feet received by the San Juan from its tributaries. This could be avoided by impounding and drawing out of the lake when the tributaries of the San Juan are not at their maximum discharge, as is necessary with 3 dams in river, or in a much more advantageous way if in arranging right of way (or concessions from the Nicaraguan Government) an exemption from claims

for damages to a high water limit of an elevation of 115 be secured. This protection from claims of damages, I believe from my observation around the lake, could be secured at a very small cost in comparison with any other method of getting such a satisfactory range of control and is strongly recommended for consideration.

Velocities in River and Canal.

A study of the velocities to be expected at certain controlling points has been made with discharges varying from 10,000 to 100,000 cubic feet per second.

In table No. 1 on page 383 are shown the velocities due to various quantities of water passing from the lake and being augmented so that the sum of the increments will be 50,000 cubic feet per second at Boca San Carlos.

An inspection of this table shows that but 10,000 cubic feet per second can be taken from the lake without causing destructive velocities in the river section of the canal. There is one exception, however, at the cut-off at Sombrero de Quero where the current in the canal is 2.26 per second. This, however, can be avoided by widening the canal 300 feet on the bottom through this cut-off.

In tables No. 2 and No. 3, it is assumed that no water is allowed to waste on the east side and we see that but 30,000 cubic feet of the 50,000 cubic feet per second which may come into the San Juan valley could be allowed to pass into the lake without exceeding the allowable limit of 2 feet per second the remaining 20,000 cubic feet would have to pass over the east side spillway.

Table No. 4 gives the velocities in the canal and river section at Conchuda cut-off and below for various quantities of water and with the water surface at different elevations corresponding to the possible elevations given by the lock systems in this section. There we see that the velocity is not excessive, except for quantities of over 30,000 cubic feet per second for the lower levels, and for the higher, 50,000 cubic feet can easily be passed.

Submerged Area.

From the available maps a computation was made of the area submerged by the pools formed by the various dams contemplated in the river as follows:

Surface of Water 110.

Dam at Ochoa, Maritime route, lake to divide	95 sq. ml.
Dam to Boca San Carlos, lake to Boca San Carlos	48 "
Dam at Lower Machuca, lake to Lower Machuca	40 "
Lake to Upper Machuca	35 "
Lake to Castillo	29 "

Surface of Water 91.6.

Lower Machuca to dam at Conchuda.	5 sq. ml.
Upper Machuca to dam at Lower	3 "

Surface of Water 73.4.

Conchuda to dam at Boca San Carlos.	1½ sq. ml.
Lower Machuca to Conchuda	3 "

As the 110-foot contour has not been run out this estimate of areas is not believed to be closer than limits of 20 per cent.

Curve Widening.

As to which side of a curve the widening should be made on it is believed that the cheaper side should be adopted. When a ship first begins to throw its helm over to follow a curve the pivotal point is in the bow and the stern is swung over the outside of the curve, as the ship gets on the curve the pivotal point moves back until it

reaches the center of gravity of the ship where it remains, and the center of gravity, which is usually near the center of length of the ship, traces the curve. As vessels in the canal would follow any given center line or curve only as closely as the different pilots will force them, it may not be considered essential to have the widening on any particular side. However, given a curve where the expense of widening is the same on either side, the preference should be given to widening on the outside for the following reasons: any widening on the outside will tend to make the radius of the effective cross section longer and the curve of the ship's course flatter.

Estimates.

Basis of Estimates.

In making estimates from the lake to Boca San Carlos the maps of the surveys made by Lieut. G. C. Hanus, U. S. N., and Assistant Engineer Francis Lee Stuart, were used.

The geological classification was made by Dr. C. W. Hayes from borings, etc., made under his direction.

Sections.—The width of the channel used in the river section was 300 feet, except through cut-offs having solid banks on both sides for a distance of more than 1000 feet, where 150 feet base was used.

Side Slopes.—The side slopes used were: in sand 3 horizontal to 1 vertical; in silt, 2 horizontal to 1 vertical; in clay, 1 horizontal to 1 vertical; in soft rock, $\frac{1}{2}$ horizontal to 1 vertical; in hard rock, $\frac{1}{8}$ horizontal to 1 vertical.

Lake.—In the lake the width of sections was from 300 feet at entrance of river to 600 feet at 30 foot curve, with slopes 5 horizontal to 1 vertical to a depth of 6 feet, then 3 horizontal to 1 vertical.

Curve Widening.—The channel was widened in river section as follows:

For curves of	3000′	rad.	increased width,	100′
" "	4000′	"	" "	75′
" "	5000′	"	" "	50′
More than	5000′	"	" "	25′

Revisions of Location.—A revised location was made and at doubtful points several lines were estimated and the cheaper, including compensation for any shortening of distance, was adopted. The line was thrown over where possible to avoid the excavation of wet rock.

Cut-offs.—The method used in determining the adoption of any location around or through the bends made by the river was as follows:

It was assumed that an extra expenditure of $250,000 could be made per mile of distance saved by cut-off line. In calculating the cut-off line when over 1000 feet long a base of 150 feet was used as against a base of 300 feet in the river.

The cost of a line around the bend was compared with the line through or across it, and the cheaper adopted. The principal cut-offs to save distance and cost were from Isle Caño to Medio Queso, and from Palo de Arco to Isla Grande, and from Sombrero de Quero to Santa Cruz. The last two were found to be cheaper than the river line, and adopted. The cut-off from Isla Caño to Medio Queso was rejected. It may be, however, that upon making a more careful investigation of this cut-off it may be found advisable to adopt it also.

Lock Systems.—The grade for the entrance of the canal on the east side will be 30 feet below mean low tide, or 30.5 below mean sea level, and the maximum elevation of Lake Nicaragua 110, making the total lift 110.5. For any system of locks the lift in each lock will be this

amount divided by the number of locks in the system.

Variants.

From inspection it was found that a feasible lock and dam system for the canal would be between a 5-lock and 8-lock system, both inclusive, and with one, two or three dams in the river. Accordingly estimates were made as follows:

5-lock	system,	1	dam	in	river,	marked....5A
5	"	2	dams	"	"	....5M
6	"	1	dam	"	"	....6A
6	"	2	dams	"	"	....6X
6	"	3	dams	"	"	....6Z
7	"	1	dam	"	"	....7A
7	"	2	dams	"	"	....7U
7	"	3	dams	"	"	....7Y
8	"	1	dam	"	"	....8A
8	"	2	dams	"	"	....8B
8	"	3	dams	"	"	....8E

The prices used for comparative purposes were:

All earth and silt excavation	$ .37	per cu. yd
Hard and soft rock	.93	" "
Dam masonry concrete	8.30	" "
Clearing	75.00	" acre.
Clearing and grubbing	100.00	" "

Locks, cost depending on lift.
Dam construction (other than masonry) depending on location.

As there was but one point where a dam must be placed in any scheme, and four other possible dam sites, to make the study exhaustive other estimates were computed, either entire or to such a point as admitted of no doubt as to which was the most desirable location for dams for the particular variant under discussion.

Estimates were made for concrete dams and of such profiles as admitted of 8 feet of water flowing over spillway. Estimates were also made for concrete locks having a capacity of 665 feet by 80 feet, and in river section with sufficient depth to admit of a range of 6 feet between maximum and minimum stages of water.

Narrow Canal Estimate.—As it may be advisable to build a canal which can handle the first business presented, and then increase the width of sections and make other betterments as the demand arises, an estimate has been made from the lake to Boca San Carlos on the 6-lock system with three dams in the river, with a width of base 150 feet throughout, passing points 2000 feet long every 5 miles and wooden locks.

Sketches.—The accompanying sketches on page 385 symbolize principal variants between the 30-foot contour in lake and Boca San Carlos on which estimates were made. The position of the dams, the elevation of the water surfaces, the length of line and the comparative costs are shown. In these estimates the cost of the Boca San Carlos dam is included but the lock dropping from the level of this dam is not.

Value of Estimates.

The estimates have been carefully made from the available data and may be considered as within limits of approximate estimates for similar work in the States.

Description of Canal Line.

Sailing Route in Lake.—The sailing route across the lake would be, with the surface less than 110, through the dredged channel passing north of Balsillas islands, a distance of 12.23 miles, then curving to the west for 1.21 miles with a 7500-foot radius to deep water, then tak-

ing a bearing of south 80° 13′ west (true) for 5.4 miles (stat.) then curving to the right for .91 miles (stat.) with 11,500-foot radius, it takes a bearing of N. 76° 48′ W. (true) for 52.63 miles (stat.) to entrance of west side canal, the total length being 71.7 statute miles.

The sailing route across the lake with the surface of the lake at 110 or more, would be through the dredged channel passing north of the Balsillas islands a distance of 12.22 miles (stat.) thence curving to the west for .81 miles (stat.) with a radius of 7500 feet to deep water, then taking a bearing of N. 75° 45′ (true) for 57.98 miles (stat.) to the entrance of the west side canal, the total length being 71.02 statute miles.

Canal Line in River.—From the lake entrance at Fort San Carlos the canal line follows as closely as possible the axis of the San Juan river for a distance of 13.1 miles to Palo de Arco where it cuts across the bend at that point. By this cut-off the length of the canal is shortened 1.3 miles. From here the line again follows the river to Sombrero de Quero, a distance of 11.2 miles where another cut-off is made, saving 1.8 miles. After leaving this point the river is closely followed, cutting across a few small points, until a distance of 40 miles from Fort San Carlos is reached. The alignment above this point is constant and included in all schemes. It is here that the different variants branch off and, following different routes, come together again at Boca San Carlos.

Variant 6A.—(The 6-lock system with one dam in the river.) Continuing from the constant, the line follows the axis of the river until the bend at Conchuda 14.2 miles below is reached. Here the cut-off saves a distance of .7 of a mile. The canal then follows the river to Boca San Carlos 56.9 miles from Fort San Carlos. Here is situated the river dam holding the lake at its summit level, while the canal line continuing across the sharp bend at this point connects with the low-level lines beyond.

Variant 6Z.—(The 6-lock system with 3 dams in the river.) Leaving the constant, the line follows the river to Lower Machuca a distance of 4.2 miles. Here is situated the first of the river dams holding the lake at its summit level, together with the first lock. In this lock the level is dropped 18.4 feet to 86.6 and following the river a distance of 10 miles to Conchuda a second dam and lock are reached; the canal at this point cutting the sharp bend on which the lock is situated. The level is here again dropped 18.4 feet to 68.2 and continues at this elevation to Boca San Carlos 2.8 miles below where the third dam and lock are situated and connecting with the low-level lines.

Arguments for and Against Variants.

The two schemes which seem to offer the best features in the river section are: a system with but one dam in the river, and the six-lock system with three dams in the river.

Variant 6A.—(One dam in the river situated near the mouth of the San Carlos river.) This gives 12 miles more of basin navigation, thus permitting a higher rate of speed for vessels than any other variant, and is equivalent to shortening the canal to some extent.

The dam itself would be the only one on the river and the largest and most important single work on the canal, and as such could be guarded against a public enemy, better than if there were several dams, each of vital importance to the operation of the canal.

It permits of more water being taken down the San Juan, and if the east side is used as a spillway could control the summit level with one foot less range than with three dams giving rise

to similar velocities. It is also cheaper than any other variant.

The argument against the scheme is that the single dam holds the basin 54 feet above the normal river, and would, if destroyed by any cause, obliterate a very large amount of canal property. The disastrous effect of such a happening, should it occur, can only be surmised. The repairs necessary would be so great that it would not be a matter of months but of years, before the canal could again be put in working order.

VARIANT 6Z.—(The six-lock system with three dams in the river.) The chief argument in its favor is that it reduces the head of water on each dam, thus removing the menace of the large single dam at Boca San Carlos.

Should any dam of this system go out it is probable that the other dams would not be affected and the river would soon regain its old form. As against this factor of safety is the extra cost of this system and the reduced efficiency of the San Juan for a waste-weir.

Respectfully submitted,

FRANCIS LEE STUART,
Assistant Engineer.

SAN JUAN DEL NORTE, NICARAGUA,
November 5, 1898.

MR. FRANCIS LEE STUART,
Asst. Engr., N. C. C., Granada, Nic.

Sir:—Answering your request for a description of the method of leveling down the San Juan river eastward from San Carlos, I beg to hand you the following. The instrument used was a Brandis transit (No. 1759) with level bubble attached to the telescope. It was set at the various stations of a zig-zag line passing from one side of the river to the other and at each setting the azimuth to the forward station was read, then the stadia distances to the back and forward stations, immediately after which readings for levels were taken on the backward and forward stations. The rod used was a board 3½ inches wide and 16 feet long graduated to tenths of a foot, simply and plainly marked. The stations were sometimes a hub driven in the ground, sometimes a stump of a tree and sometimes a pile driven in the mud and firmly braced. Below Savalos the stations were nearly all hubs but above that point they were nearly all stumps or piles. The instrument was set over the latter by nailing the board to which it is attached while in the box to the top of the stump or pile and screwing it to the board. The nails for center were left projecting about ⅛ inch to make a definite point for the level rod. The length of sights was from 800 feet to 2400 feet, an average being perhaps somewhere between 1100 feet and 1400 feet. Readings for levels were taken at each set-up so that two sets of notes were kept and two determinations of the height of each station secured, except between El Castillo and San Carlos, when level readings were only taken at every other set-up and only one line of levels taken; what was done will perhaps be made clearer by the following explanation:

Starting with the instrument at "a" take a backsight on the B. M. and foresight on "b" and also foresight on "a" by measuring down from the cross-hairs. This gives one elevation of "a" and one of "b." Then, after having previously set the instrument half-way between B. M. and "a" and obtained a second elevation of "a," set at "a" using the second elevation of "b," take a backsight on it and a foresight on "c" and one on "b." We now have two elevations of "b." Then set at "c" and using the first elevation of "b" take a backsight on it and foresight on "d" and "c" and so on. The

readings taken when the instrument is at "a," "c," "e," etc., form one set of notes and constitute one line of levels. Those taken with the instrument at "o," "b," "d," "f," etc., form another set of notes and another line of levels. Each set of notes has the elevation of each point and the average is taken. It will be noticed that what is a backsight on one line is a foresight on the other line, and vice versa, so that errors coming from unequal foresight and backsights due to imperfect adjustment for collimation are perfectly eliminated.

While this leveling was being done the weather was nearly always cloudy and cool. Few sights were taken when there was any hot sunshine. The sights were nearly all across the water surface and the temperature of air, earth and water was practically the same.

In Appendix IX is a table showing the results of this leveling compared with that obtained by the Precise Level party between Ochoa and San Carlos. The initial difference of elevation at Ochoa was 0.500 and this difference varies by very small amounts as the different points were touched until a point is reached above Castillo, when the discrepancy rises to 0.36 at San Carlos. Over this part only one line of levels were run and perhaps some allowance should be made on account of its being at the beginning of our work.

Respectfully,

S. S. Evans,
Assistant Engineer.

MEMORANDUM IN REFERENCE TO FRANCIS LEE STUART'S REPORT UPON THE SAN JUAN RIVER.

Distances and fall in river supplied by A. Onderdonk from maps and notes of the Nicaragua Canal Commission's Surveys of San Juan and Colorado rivers. The distances are taken along the *axis* of the river.

The elevation of the water in Lake Nicaragua was taken at 104.4 which was its elevation at the time the surveys were commenced, and the elevation of the sea was taken at 0.0.

The following is a table of the distances and elevations:

	Dist. Miles.	Elev. Feet.
Lake Nicaragua—San Carlos	0.00	104.4
Mouth of Savalos river	27.16	99.0
Bottom Toro rapids	28.86	91.7
Beginning Castillo rapids	36.84	90.5
End Castillo rapids	37.22	84.5
Punta Gorda	39.30	82.0
One mile below Machuca	49.92	56.0
Boca San Carlos	64.71	55.0
Rio San Juanillo	97.73	25.0
Boca Colorado	103.01	21.0
Sea via San Juan river	121.66	0.0
Sea via San Juan and Parada creek	115.04	0.0
Sea via Colorado river	126.71	0.0
Sea via Colorado and Caño Bravo	122.71	0.0

Andrew Onderdonk,
Assistant Engineer.

TABLE No. 1 SHOWING VELOCITIES IN RIVER AND CANAL SECTIONS, ASSUMING VARIOUS QUANTITIES OF WATER AS PASSING FORT SAN CARLOS, AND BEING AUGMENTED PROPORTIONALLY TO THE DISTANCE SO THAT THE SUM OF THE INCREMENTS WILL BE 50,000 CUBIC FEET PER SECOND WHEN BOCA SAN CARLOS IS REACHED.

Computations made for an elevation of water surface at 110.

Quantity passing Fort San Carlos	10,000		20,000		30,000		33,000		40,000		50,000		
Location.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Remarks.
Station 268	15,000	0.99	25,000	1.64	35,000	2.30	38,000	2.50	45,000	2.97	55,000	3.62	
" 680	20,000	1.25	30,000	1.89	40,000	2.50	43,000	2.70	50,000	3.14	60,000	3.77	
" 1265	30,000	1.74	40,000	2.32	50,000	2.91	53,000	3.08	60,000	3.48	70,000	4.07	
Cut-off Palo de Arco													
River	11,190	0 88	16,170	1.27	21,140	1.66	22,630	1.78	26,120	2.05	30,700	2.41	
Canal	11,310	0.98	16,330	1.42	21,360	1.86	22,870	1.99	26,390	2.30	31,800	2.77	
Cut-off Sombrero de Cuero													
River	17,230	1.66	22,160	2.14	27,090	2.62	28,550	2.76	32,020	3.10	36,900	3.56	
Canal	17,770	2.74	22,840	3.53	27,910	4.32	29,450	4.55	33,980	5.11	38,100	5.88	Width on bottom 150′.
River	12,470	1.20	16,040	1.54	19,610	1.88	20,670	1.99	23,180	2.22	26,700	2.59	
Canal	22,530	2.26	28,960	2.91	35,390	3.56	37,330	3.75	41,820	4.21	48,300	4.86	Width on bottom 250′.
Cut-off Conchuda													
River	43,350	1.20	50,580	1.40	57,810	1.60	59,900	1.65	65,040	1.80	72,200	2.00	
Canal	16,650	1.44	19,420	1.68	22,190	1.92	23,100	2.00	24,960	2.16	27,800	2.41	

Q=Cubic feet per second. V=Velocity, feet per second.

TABLE No. 2 SHOWING VELOCITIES IN RIVER AND CANAL SECTIONS, ASSUMING THE CURRENT AS STARTING AT MACHUCA AND BEING AUGMENTED PROPORTIONALLY TO THE DISTANCE SO THAT THE SUM OF THE INCREMENTS SHALL BE 30,000 AND 40,000 CUBIC FEET PER SECOND WHEN FORT SAN CARLOS IS REACHED.

Computations made for an elevation of water surface at 110.

Sum of increments at Fort San Carlos.....	40,000		30,000		
Location.	Q.	V.	Q.	V.	
Cut-off Sombrero de Cuero					
River	7,370	0.69	4,900	0.48	
Canal	7,630	1.18	5,100	0.79	Width on bottom, 150′.
River	5,330	0.51	3,070	0.29	
Canal	9,670	0.97	6,930	0.69	Width on bottom, 250′.
Cut-off Palo de Arco					
River	13,680	1.07	10,150	0.80	
Canal	13,820	1.20	10,250	0.90	
Station 1265	19,000	1.10	14,700	0.85	
" 680	29,000	1.82	22,000	1.38	
" 268	36,000	2.37	26,700	1.75	

Q=Cubic feet per second. V=Velocity, feet per second.

TABLE No. 3 AS ABOVE EXCEPT THAT THE CURRENT IS ASSUMED TO START FROM BOCA SAN CARLOS, AND THAT THE SUM OF THE INCREMENTS AT FORT SAN CARLOS SHALL BE 50,000 AND 30,000 CUBIC FEET PER SECOND.

Sum of increments at Fort San Carlos.....	50,000		30,000		
Location.	Q.	V.	Q.	V.	
Cut-off Sombrero de Cuero					
River	11,760	1.13	7,100	0.69	
Canal	11,240	2.74	6,900	1.06	Width on bottom 150′.
River	8,000	0.79	5,000	0.49	
Canal	15,000	1.50	9,000	0.90	Width on bottom 250′.
Cut-off Palo de Arco					
River	18,890	1.48	11,350	0.89	
Canal	18,610	1.63	11,150	0.97	
Station 1265	30,000	1.74	18,000	1.05	
" 680	40,000	2.50	24,000	1.50	
" 268	45,000	2.97	27,000	1.77	

TABLE No. 4 SHOWING VELOCITIES IN RIVER AND CANAL SECTIONS BELOW MACHUCA FOR VARIOUS QUANTITIES AND ELEVATIONS OF THE WATER SURFACE.

Q=100,000.

Elevation W. S.....110			105		91.6		82.4		68.2	
Location.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.
Cut-off Conchuda										
River.....	72,200	2.01	73,300	2.23	60,100	2.49	52,400	2.73	50,000	2.77
Canal	27,800	2.36	26,700	2.70	39,900	3.37	47,600	4.10	50,000	4.33
Station 3052	100,000	2.98	100,000	3.24	100,000	4.10	100,000	4.48	100,000	6.07

Q=80,000.

Elevation W. S.....110			105		91.6		82.4		68.2	
Location.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.
Cut-off Conchuda										
River.....	57,760	1.61	58,640	1.78	48,080	2.03	41,920	2.21	40,000	2.22
Canal	22,240	1.89	21,360	2.16	31,920	2.70	39,080	3.28	40,000	3.46
Station 3052	80,000	2.38	80,000	2.59	80,000	3.28	80,000	3.58	80,000	4.86

Q=50,000.

Elevation W. S.....110			105		91.6		82.4		68.2	
Location.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.
Cut-off Conchuda										
River.....	36,100	1.00	26,650	1.11	30,050	1.25	26,200	1.37	25,000	1.39
Canal.....	13,900	1.18	13,350	1.35	19,950	1.68	23,800	2.05	25,000	2.16
Station 3052	50,000	1.49	50,000	1.62	50,000	2.05	50,000	2.24	50,000	3.04

Q=30,000.

Elevation W. S.....110			105		91.6		82.4		68.2	
Location.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.
Cut-off Conchuda										
River.....	21,660	0.60	21,990	0.67	18,030	0.74	15,720	0 82	15,000	0.83
Canal.....	8,340	0.71	8,010	0.81	11,970	1.11	14,280	1.23	15,000	1.30
Station 3052	30,000	0.89	30,000	0.97	30,000	1.23	30,000	1.34	30,000	1.82

Q=Cubic feet per second. V=Velocity, feet per second.

SKETCHES OF VARIANTS.

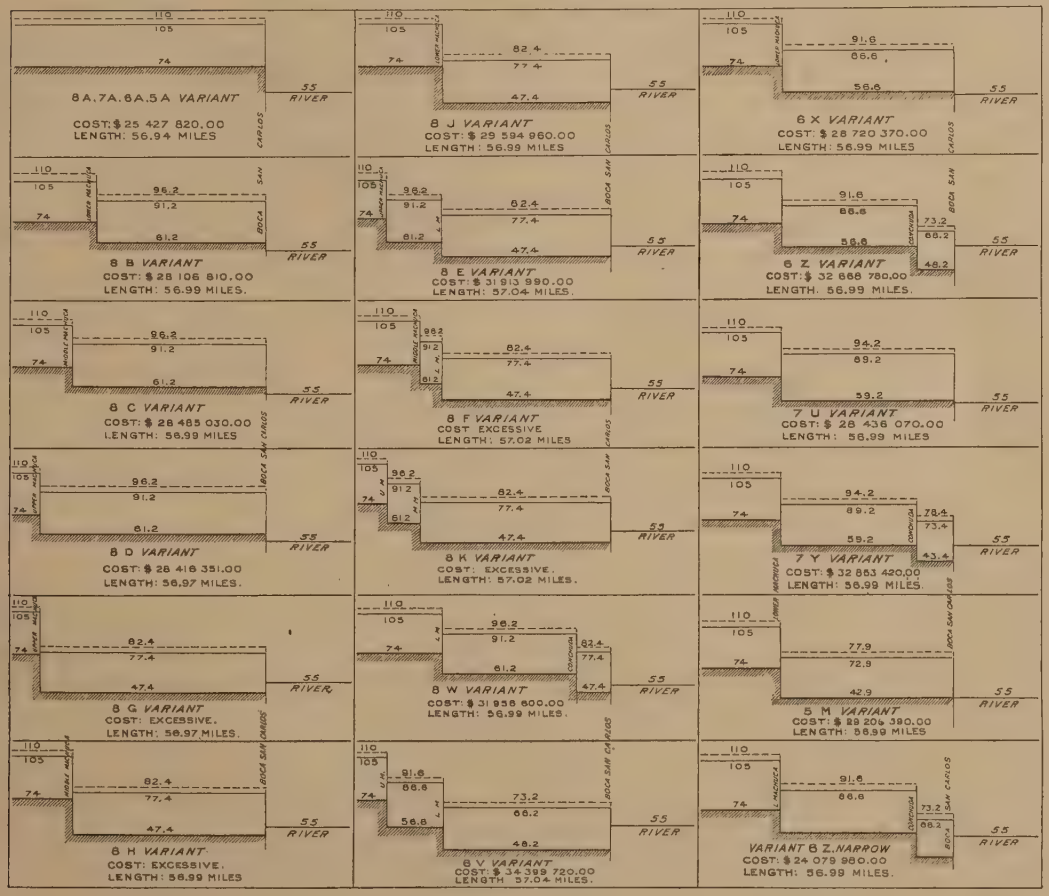
Lengths of Variants are from Sta. O at Fort San Carlos to Boca San Carlos.

Prices used for determining comparative costs.

All earth and silt excavation.....	$ 0.37	per yard.
Hard and soft rock.....	0.93	"
Dam Masonry, concrete.....	8.30	"
Clearing	75.00	per acre.
Clearing and grubbing	100.00	"

Lock cost depending on lift.

Dam construction other than masonry depending on location.



APPENDIX VI

REPORT OF H. H. TRUNDLE

Assistant Engineer

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APPENDIX VI

WASHINGTON, D. C., May 5, 1899.

MR. E. S. WHEELER,

Chief Engineer, Nicaragua Canal Commission, Washington, D. C.

Sir:—I have the honor to submit to you the following general report of work done under my direction for the Nicaragua Canal Commission of 1897.

Very respectfully,

H. H. TRUNDLE,
Assistant Engineer.

REPORT OF SERVICE WITH THE NICARAGUA CANAL COMMISSION.

In compliance with instructions from Rear-Admiral John G. Walker, President of the Commission, I reported at the Commission's headquarters in New York, November 25, 1897. I there received instructions to go to the offices of the Maritime Canal Company and take copies of such notes as would be of use in retracing this canal company's location between Greytown (San Juan del Norte) and Ochoa. I was engaged on this work until December 5. During this time I found the secretary of the Canal Company, Mr. Thos. B. Atkins, very courteous and accommodating.

On December 5, we sailed from New York on the U. S. gunboat "Newport" and anchored at Key West December 11, about 11 A. M., where we remained until the following evening, coaling. About 6 P. M., December 12, we weighed anchor and sailed for Greytown arriving at that port at 11 A. M., December 17. We had pleasant weather during the entire trip which was very fortunate for us, since owing to the crowded condition of the ship, we would otherwise have been very uncomfortable.

Immediately after casting anchor off Greytown I was detailed to accompany the disbursing officer ashore and assist in arranging for temporary quarters for the expedition. We crossed the Greytown bar in one of the tugs of the Caribbean and Pacific Transit Company, manned by Carib Indians who showed themselves to be very efficient boatmen. After crossing the bar we took canoes and proceeded up one of the channels through which the San Juan river empties its waters into the Caribbean sea, and through Greytown lagoon to Greytown. This channel is very tortuous, about fifty feet wide and three miles long.

After enjoying a good dinner at Sandusky's, Mr. Boyd Ehle and myself were instructed to go to the quarters built by the Canal Company in 1889 at La Fé and report on their adaptability as temporary quarters for the expedition. We found the buildings in fairly good condition with the exception of the stoops or porches, which had been exposed to the weather and were considerably decayed. The framework of these buildings is of pine, the roof and sides being covered with corrugated galvanized iron. They rest on piles which are heavily

coated with pitch. The first or lower floors are about four feet above the ground, thus allowing a current of air beneath them. The framework for the buildings was, I understand, shipped ready framed from the United States. After looking over the largest building as carefully as circumstances would permit, we decided that it was large enough, and with some light repairs would be safe as temporary quarters for the engineer force.

When this report was made to the disbursing officer, he instructed me to employ the necessary labor and prepare quarters for the reception of the entire engineer force on December 18. The quarters were gotten in shape and a meal prepared by 2.30 P. M., Mr. Ehle having attended to getting provisions, cooking utensils, etc., from the Commission's supply at Greytown and shipping them to La Fé. Lieut. G. C. Hanus, U. S. N., arrived with the first detachment of engineers from the "Newport" about 1.30 P. M., and took charge of the camp.

On December 22, I received your letter of instructions, dated December 21, directing me to retrace the Canal Company's location between Greytown and Ochoa and assigning me assistants for the work. The object of this work being to verify the Canal Company's maps and profiles, establish a base line from which surveys for changes in location could be made if found necessary or desirable, and to collect sufficient data to enable the Commission to make an independent estimate over the route.

The interval between December 22, and December 30, was employed in getting together camp and instrumental outfits, adjusting instruments, procuring laborers and exploring some of the line in immediate vicinity of Greytown. Actual work in the field was commenced December 30.

The canal between Greytown and the site for Lock No. 1 is almost entirely in swamp and for this reason it was considered unnecessary to run the center line through this portion. Instead, we retraced the center line of the railroad as far as it had been constructed, which is about 11½ miles. Elevations of swamps on either side of the railroad were taken at frequent intervals, and at longer intervals, cross lines were run over to the center line of the canal, thus verifying the elevation of various points on the canal line. The railroad line was joined to the canal location at the edge of swamp just east of the proposed site for Lock No. 1, by a cross line; by this means we were enabled to verify the length of the canal between Greytown and this junction. West of this junction the center line of the canal was retraced and verified all the way to Ochoa.

Methods Adopted in the Work.

All angles were measured carefully with a transit, deduced bearings being carried through as a check to the reading of the angles. Owing to the density of the forest and the almost incessant rain or cloudiness it was impracticable to check the work as often as I would have liked by sidereal observations. Our transits were not fitted with solar attachments.

The measurement was done almost exclusively with steel chains 100 feet long. These chains were checked and adjusted by comparison with a steel tape at intervals of about two weeks. Especial care was taken in the chaining, plumb bobs being used on all rough and broken ground. Quite a number of the Canal Company's points were found by which we were enabled to compare our measurements with that of the company. At a few points, where the line ran in the Deseado river, the stadia was used, being checked by backsight readings.

Elevations of surface were taken with a wye level and target rod at intervals of 100 feet and at such intermediate points as were necessary in order to produce a close and accurate profile. While we were retracing this line Mr. Stephen Harris was running a "precise level" line over practically the same ground and we were able to check up on his elevations at intervals of from one to five miles. The greatest difference per mile which occurs between our levels and those of the precise level party, is shown by Mr. Harris' report to be between our initial bench mark, in the company's machine shops at Greytown, and a point on the railroad line 4.39 miles out of Greytown. This difference amounts to about 59/1000 of a foot per mile, our elevation being the lower.

When our line was found to be only a short distance from the Canal Company's location, such distance was noted and cross sections were taken at sufficiently close intervals to enable us to plot an accurate profile directly on the Canal Company's line. Other cross sections were taken to verify the contour maps of the line. At no point on the route was our line more than 30 feet from that of the Canal Company.

In making this survey we used ten camps, their average distance apart (measured on the trails) was about three miles. They were not, however, placed at equal intervals, but at longer or shorter intervals to equalize for the difficulties in walking or packing through the country. The greatest distance between any two camps was 7½ miles, while the least was 1½ miles. All camps, with the exception of one, were built by independent forces organized for the purpose. They were without sides or walls and were covered with thatch made of some one of the many varieties of palm found in this section. That known as the "Suita Palm" is one of the best for the purpose and is tied to the frame work of the roof with a species of vine known as "bejuca."

In making this survey, about 60 miles of line was run, which may be divided as follows:

Retraced railroad line	11.4 miles.
Retraced canal line	22.1 "
Tie, auxiliary and topography lines	26.5 "

The transit party reached Ochoa May 7, 1898. Owing to the sickness of our levelman during the latter part of the work, the level party did not reach Ochoa until May 15.

Results of Survey.

(1) The maps and profiles published by the Canal Company covering this section were found to be correct and reliable.

(2) The location was found to be good for the adopted system of locks and dams.

(3) Sufficient data was obtained to enable the Commission to make an independent estimate through this section.

This route has been so thoroughly discussed in previous publications that I deem it unnecessary for me to make any further description of it.

Preliminary Lines for Low-Level Canal.

The next work assigned me was the running of preliminary line from the mouth of Embankment creek in an easterly direction toward Greytown. Embankment creek, as will be seen by reference to a map of this part of the work, is a short distance down the San Juan river from Ochoa. This work was commenced May 11, and the routes of the preliminary lines run by me may be briefly described as follows: The first line begins on the bank of the San Juan river near the mouth of Embankment creek

and follows it to its head. It then crosses a divide into the valley of the Caño Leonora and follows this to its junction with the Rio Danta in Florida lagoon. From this point the line passes through the Florida lagoon and down the Rio Danta to within about a mile of its mouth; here the line leaves the Danta and crosses a strip of land about two miles wide to the Rio San Francisco; it then crosses the Rio San Francisco and follows down the southern slope of the San Francisco hills to their eastern end where it joins with the preliminary line run by Assistant Engineer Boyd Ehle.

After joining with Mr. Ehle's work at the San Francisco hills, we moved camp down the San Juan river and ran the necessary lines for filling in a gap in the topography between the eastern slope of the Sarapiqui ridge and a point about 1½ miles east of the San Juanillo river, on Mr. S. S. Evans' preliminary line from Greytown. About 3½ miles of this work was done by Mr. Evans' party under my direction, Mr. Evans at the time being unable, on account of sickness, to superintend the work.

Methods Employed on Preliminary Lines.

All preliminary and many of the principal topography lines were run with the same care and accuracy as was used in retracing the Canal Company's location. On minor topography lines the compass was used generally. The hand level was used for some topography, though not to any great extent, or on any of the principal topographical base lines.

In taking the topography, I endeavored to get sufficient data to make an accurate contour map which would cover at least 1000 feet on each side of what seemed to be the rational location for the canal through the section traversed. At all points where there was any doubt as to the proper location, alternate lines were run. Wherever it could be conveniently done these surveys were tied by cross lines to points on the survey of the San Juan river.

We completed the field work and moved into headquarters near La Fé August 28, where we remained until September 16, this interval being employed in plotting up field notes.

On September 16, we sailed from Greytown on the Atlas Line steamer "Altai," arriving in New York September 27, and then proceeded to Washington where offices had been procured.

Office Work.

The survey notes arrived in Washington October 6, and I was assigned the making of locations and estimates for a low-level canal between the eastern slope of the Sarapiqui ridge and the point at which the finally adopted location enters the San Juan river on the west side of the Boca de San Carlos ridge. Later I was assigned the work of making plans and estimates of cost of masonry locks having various lifts, and of masonry dams above Boca de San Carlos and at Machuca rapids, having different crest elevations; this data being necessary for making comparative estimates on locations for different systems of locks and dams.

The first few weeks in office were devoted largely to the plotting and comparison of topography notes and the making of a complete topographical map covering the entire section through which the locations were to be made. Practically all of the topography notes had been plotted on brown paper maps before we left Nicaragua; they were, however, in disjointed sections and had to be combined.

Locations and estimates were made for systems of locks and dams, east of Lake Nicaragua as follows:

For five locks with one and two dams.

For six locks with one, two and three dams.

For seven locks with one, two and three dams.

For eight locks with one, two and three dams.

The above estimates, eleven in all, were made for a canal 150 feet wide at bottom. Some alternate estimates were also made on these systems having the width at bottom 100 feet through hard rock sections and 150 feet elsewhere.

An additional estimate was made for a canal using a system of six locks and three dams east of Lake Nicaragua and having a bottom width of 100 feet. In this estimate passing points, having a bottom width of 150 feet and length of 2000 feet, were provided for at intervals of about five miles.

In selecting a location, the one used for estimates has been adopted only after a comparison with all alternate lines which have suggested themselves, and often only after complete alternate estimates have been made. In general, the location adopted for making the estimate for a system of six locks and three dams has been found to be best for any of the above mentioned systems. For some, slight divergences are necessary in order to secure suitable locations for locks. The grades have been so adjusted as to make the lifts of all locks in each system equal at maximum stages of water.

All work has been done on contour maps showing 10-foot contours and plotted to a scale of 400 feet to the inch. All estimates of excavation have been derived from plotted cross sections, the areas of which have been taken off with planimeters. Profiles are plotted with a vertical scale of 20 feet to an inch and horizontal scale of 400 feet to an inch and show the geological classifications as determined by Dr. C. W. Hayes of the U. S. Geological Survey, from borings and observations in the field.

It is of course impossible to determine, intelligently, the proper number of locks and dams to be used on the entire system east of Lake Nicaragua, from results obtained from estimates on that section of the line between the Sarapiqui and San Carlos ridges. For this section alone, however, the results seem to point to the selection of either the six- or eight-lock systems, for any number of dams. Both of these systems show very small amounts of high embankment and are everywhere high enough above the San Juan river to be out of danger of floods. There is a very small portion of the embankment on either of these systems that would have a head exceeding 15 feet of water against it, and over a large percentage of it the head would be less than 10 feet. The eight-lock system gives a little less head of water against embankments and costs something more. If only one dam should be used, the eight-lock system would have the disadvantage of having one double lift lock.

Waste-Weirs.

Estimates for this section include about 2800 lineal feet of waste-weirs designed for the discharge of the surplus waters of the various basins traversed.

The general type of construction consists of a concrete core and crest backed with a rock fill. Sufficient length of crest being given to allow for the maximum discharge, with a depth of water not exceeding one foot over the crest.

Locks.

The locks are estimated to be built of concrete and have steel gates; a guard gate is provided for at each end of each lock, for repair purposes. The general dimensions are: width between side walls 80 feet; length between corresponding

points on gates 665 feet; and depth of water over sills 30 feet. The data for estimates and the general design for the locks were derived from the lock recently built by the U. S. Government for the "St. Mary's Falls Canal."

Dams.

All masonry dams were designed and estimated to be constructed of concrete. They have ogee crests and are founded on hard rock foundations.

In order to avoid the necessity for excessive depths in canal and locks it is evident that the surfaces of pools above dams should vary as little as possible. For this reason all the available crest of each dam has been used for spillway.

For a system in which only one dam is used, plans and estimates have been made for gates, similar to those used on the Chicago drainage canal, placed on the crest of the dam and capable of controlling the level of Lake Nicaragua between the elevation of 105 and 110 feet above the Caribbean sea; this is also true of the dam nearest the lake in any system of locks and dams.

By far the greatest difficulty to be encountered in the construction of any of these dams will be that of coffer-dams at Boca de San Carlos, the maximum depth of hard rock below mean water being about 70 feet. It is believed, however, that ample allowance has been made to cover any possible contingencies that may arise from that source.

Canal Embankments.

It was endeavored to so make the locations and fix the grades as to eliminate, as far as possible, embankments supporting heavy heads of water. Care was also taken to avoid placing embankments on poor foundations, and for this reason the locations were, in many places, thrown out of what would otherwise have been their proper position.

It is proposed to build the embankments to an elevation of eight feet above the water in the canal opposite. They will, where practicable, be placed, so as to give a berm fifty feet in width between the excavation and embankment. Since no embankment will be required on the north side of the canal through this section, it will be readily seen from observation of maps and profiles that there is ample material from excavation for making an embankment on the south side 150 feet wide if necessary, without long haul.

Where there will be a head of more than 15 feet of water against embankments they are designed to be made thicker than at other points by an amount depending upon the head of water to be supported; as an additional precaution sheet piling and clay are also to be used in these places. All sheet piling is to be driven to a depth of at least five feet below the bottom of the canal and to extend, as a rule, well into the underlying clay.

Where the embankment encroaches on the San Juan river and is likely to be eroded at high stages of water, it is intended to be covered on the exposed side with stone from the canal excavations. At all points where this form of construction is necessary, the rock for the work is found in cuts in the immediate vicinity. Spoil banks for the excess of material from excavation will be made in the swamps traversed and ravines crossed.

Selected Route.

The Commissioners have adopted the system of six locks and one dam east of Lake Nicaragua with the dam located a short distance above the

mouth of the San Carlos river. That part of the location for this system through the section on which I have made the estimates may be briefly described as follows:

It begins on the eastern slope of the Sarapiqui ridge a distance of 22.32 miles from the seven-fathom curve, in the Caribbean sea near Greytown. The canal surface at this point will be at an elevation of 54.75 feet above the Caribbean, it being on the reach between Lock No. 3 and Lock No. 4. Thence the line runs in a westerly direction generally parallel to the San Juan river passing through the Sarapiqui ridge, along the southern slope of the Tamborcito ridge, through a depression in the Tambor Grande ridge and along the southern slope of the San Francisco hills to the San Francisco river, which it crosses about 1400 feet above its mouth. From this point the line runs in a westerly direction, a distance of about two miles, across a strip of land containing some small hills to the Danta river, which it strikes about a mile from its mouth, following the valley of the Danta up to, and through Florida lagoon and thence up the Caño Leonora to its headwaters; the location having been thrown out of the axis of the Danta valley in some places to improve the alignment and furnish better foundations for embankments.

Lock No. 4 is located in the divide between the Caño Leonora and Embankment creek and with a lift of 18.42 feet gives an elevation of 73.17 feet for the surface of the reach above it.

Leaving Lock No. 4 the line passes down the valley of Embankment creek to within 1500 feet of its mouth, where it diverges from the valley by a curve to the right, passing through some rather high hills, it runs in a westerly direction generally parallel to the San Juan river, crosses the Caño Machado about 200 feet above its mouth and passes on to the site for Lock No. 5.

Lock No. 5 is located in a hill about two miles west of Caño Machado and with its lift of 18.41 feet gives an elevation of 91.58 feet for the surface of the reach above it.

Leaving Lock No. 5 the line passes on to the site of Lock No. 6, crossing some hills and small streams. This reach, it will be noted, has some high embankments; but since we have an abundance of good material here and the underlying clay is within easy reach of sheet piling, it is believed that no great amount of trouble will be encountered in making them.

Lock No. 6 is located in the eastern side of the Boca de San Carlos ridge and with a lift of 18.42 feet makes an elevation of 110 feet for the surface of the reach above it. This elevation is the proposed maximum for the surface of Lake Nicaragua. Even if the surface of Lake Nicaragua should be allowed to reach an elevation of 112 feet the lift for this lock would not exceed that given above, since the water surface in the San Juan river would have a slope from the lake amounting to as much as, or more than, two feet. The minimum lift of this lock would be five feet less than its maximum.

Leaving Lock No. 6 the line passes through the Boca de San Carlos ridge and enters the valley of a small stream which it follows to its junction with the San Juan river. The bottom grade of this portion of the canal is placed at an elevation of 74 feet so as to allow for a depth of 30 feet of water in the canal when the surface of the lake is at an elevation 104.

For a description of the location westward from this point I would respectfully refer you to the report of Francis Lee Stuart, assistant engineer.

The total length of canal between the eastern

slope of the Sarapiqui ridge and the point at which the canal enters the San Juan river west of Boca de San Carlos ridge is 21.59 miles. About 38.5 per cent. of this line is located on curves. The minimum radius of curvature used is 3820 feet.

Observations on that Portion of Nicaragua Between Greytown and Ochoa.

Climate.—The climate of this country is usually considered to be unhealthful by persons not acquainted with it. We found it particularly healthful for a tropical country. We were in the field from December 30, 1897 until August 28, 1898 and during that time had not a single serious case of sickness, notwithstanding the fact that we were at work in rain and swamps about three-fourths of the time.

Most of us had one or more light attacks of fever, but they invariably succumbed readily to medical treatment. These fevers were, I think, usually if not always, caused by the kind of water drunk. I believe if boiled water had been strictly adhered to, we would have had little or no trouble from fevers. Officers of my party lost about seven per cent. of the time from field work but were seldom too sick for office work in camp. It should be remembered that all these men had to be acclimated. It is likely that extensive excavation would make the country more unhealthful.

The rainfall is excessive and retards to a considerable extent any engineering work done. In instrumental work short sights have to be resorted to and trouble is experienced from clouding of lenses. The average rainfall decreases gradually in going westward from the Eastern Divide. There are wet and dry seasons, but they are divided by no finely drawn lines as is the case in other parts of the country.

The temperature varies but slightly and it is very seldom excessively warm. It is very debilitating, however, and in my opinion, a man cannot stand more than three-fourths of the physical exertion possible in a temperate climate.

Vegetation.—As would be expected in a wet country within the tropics, the vegetation is very dense and varied. It is impossible to make any progress in the forest without the use of a machete or similar implement for cutting away the tangled mass of undergrowth, which of course retards work very much. In the swamps the growth is largely made up of the many varieties of palm. On the hills we find a great variety of timber. Most of it is soft and unfit for use as lumber, though a good deal of it possesses sufficient strength and durability to make it of use in the event of the construction of the canal, among which may be mentioned the following:

The Manwood, which is very hard, heavy and durable, is said to last for thirty years in foundations but is found only in limited quantities.

The Cedar, which is soft, light and durable and grows to be very large, hardens somewhat after working and is found only in small quantities in this section.

The Gavilan, which is found in large quantities and is hard but not durable, is used to a considerable extent for railroad ties, and its average life in this capacity, under well-ballasted track, is about a year and a half.

There are quite a number of other woods found in this section that, with proper facilities for working them, may be profitably used for structures of a very temporary character.

Plaintains and bananas are the most useful fruits grown in this section; the natives live on them almost entirely. They are grown only in quantities sufficient to supply the limited demand of the Greytown market. With increased

demand, however, they would be grown in large quantities. Cocoanuts grow well along the coast. Few garden products thrive owing to the excess of rain.

Geological Formation.—I wish only to touch on this subject where it affects directly the construction of a canal through this section, as I feel sure that it has already been ably treated by our geologist, Dr. C. W. Hayes.

The swamps, after getting back three or four miles from the coast are composed of silt or alluvium. From observations of the banks of streams I would class this as a fairly good material for banks supporting small heads of water. I would not like to depend on it for embankments against large heads of water. The banks of the larger streams traversing these swamps stand at steep slopes, are comparatively hard, show little or no sign of seepage and are above the surrounding swamp. If we go back from the bank a short distance we find the ground covered with water to a depth of from one to three feet and very soft. This seems to show that the material hardens when drained and is fairly impervious to water.

The hills, as is shown on the classified profiles, are largely composed of clay and rock. The clay is red in color and on the surface shows little gravel. Its ability to stand at steep slopes in excavation is demonstrated on the railroad work done by the Canal Company in 1890. Here we found cuts twenty-five feet deep having slopes of about $\frac{1}{4}$ horizontal to 1 vertical. These slopes, which have stood for more than seven years, were apparently perfectly stable and the shovel and pick marks were plainly visible. This clay would make good puddle.

The hard rock noted in out-crops, apparently, has no cleavage. It would not be suitable for cut stone masonry but would do well for concrete. I doubt if it could be gotten out in shapes suitable for rubble masonry without great expense.

Labor.—The laborers used for prosecuting the surveys were Jamaica negroes and Nicaraguan natives. The natives were found to be very much more satisfactory for this work. They are more adept in the use of the machete, better boatmen and packers, more reliable and amenable to discipline and very much more healthy than the Jamaican negroes. The negroes I had employed lost about seven per cent. of the time on account of sickness while the natives lost only about two per cent. from this cause. The natives, however, are too light in build to be able to stand very heavy work.

In the event of the construction of the canal practically all of the labor will have to be imported and it is likely that Jamaica negroes will be found best suited for work on the canal. They are acclimated to the tropics, available in considerable numbers and with proper sanitary and police regulations could probably be kept healthy and made to do good work. Skilled labor would have to be imported from some other source.

Animal Life.—There are quite a number of animals in this section, but they are seldom seen on account of the density of the forest. Among those most often seen may be mentioned monkeys, wild hogs, pisotes, wild cats and dantas. Pumas are very rarely seen. Alligators are numerous in the ponds and lagoons. While the snakes are probably abundant they are seldom seen and, as a rule, are very sluggish. The venomous varieties most usually seen are the tamagas, tobobas and coral snakes. All the larger streams abound in fish. In the San Juan we find a number of fresh water sharks, the largest I saw was probably six feet long. Among

the game birds found are pigeons, ducks and wild turkeys. Owing to the density of the undergrowth and consequent difficulty in approaching it, game cannot be depended upon as a food supply. Insects of almost every conceivable species are found here in abundance. Among those most objectionable may be mentioned mosquitoes, alligator ants, wasps, gnats, ticks and jiggers or chigoes. Domestic cattle, hogs and goats are raised only to a small extent.

I append lists of assistants I have had both in the field and office work, showing their positions on the party and the dates between which they were employed.

Mr. Norris was my first assistant on the retracing of the Canal Company's route and did his work faithfully and well.

Mr. Hankins was my first assistant on the preliminary work for the low-level canal. While this work was in progress it was necessary for me to be away from the party a great deal. During my absence Mr. Hankins assumed charge of the party and with his long experience in railroad location did work that was highly satisfactory in every way.

Mr. Whistler was my principal assistant on the office work and has proved to be thoroughly satisfactory in every particular.

List of Assistants in Field Work.

Name.	Position.	Dates of Employment.		
A. J. Norris,	Transitman,	Dec. 22, 1897	to	May 16, 1898.
Dion Martinez,	Levelman,	Dec. 22, 1897	"	May 1, 1898.
W. A. Smith,	Rodman,	Dec. 22, 1897	"	June 15, 1898.
P. J. Brune,	Chainman,	Dec. 22, 1897	"	Aug. 28, 1898.
Loughlin McNeil,	Chainman,	Dec. 22, 1897	"	May 8, 1898.
R. H. Morrin,	Levelman,	May 1, 1898	"	July 23, 1898.
H. C. C. Shute,	Chainman,	May 14, 1898	"	July 9, 1898.
R. C. Wheeler,	Levelman,	June 15, 1898	"	Aug. 28, 1898.
L. Hankins,	Transitman,	May 15, 1898	"	Aug. 28, 1898.

List of Assistants on Office Work in Washington.

Name.	Position.	Dates of Employment.		
P. J. Brune,	Computer,	Oct. 6, 1898	to	Dec. 31, 1898.
A. J. Norris,	Draughtsman and Computer,	Oct. 20, 1898,	"	Apr. 1, 1899.
P. W. Evans,	Computer,	Oct. 11, 1898	"	Dec. 19, 1898.
Jno. T. Whistler,	Asst. Engineer,	Oct. 17, 1898	"	the present.
W. D. Hines,	Draughtsman,	Feb. 1, 1899	"	Mar. 4, 1899.
Thos. F. Boltz,	Computer,	Mar. 18, 1899	"	the present.
W. J. Maher,	Computer,	Mar. 20, 1899	"	Apr. 27, 1899.
W. C. Frye,	Draughtsman,	Mar. 23, 1899	"	Apr. 5, 1899.
Jno. B. Johnston,	Computer,	Apr. 1, 1899	"	the present.

APPENDIX VII

REPORT OF BOYD EHLE

Assistant Engineer

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APPENDIX VII

WASHINGTON, D. C., April 15, 1899.

MR. E. S. WHEELER,

Chief Engineer, Nicaragua Canal Commission, Washington, D. C.

Sir:—Referring to your letter dated February 21, 1899, I have now the honor to transmit, herewith, a report of my "entire operations connected with the Nicaragua Canal Commission."

I am Sir,

Your obedient servant,

BOYD EHLE,

Assistant Engineer.

REPORT OF SERVICE WITH THE NICARAGUA CANAL COMMISSION.

Under the direction of the Commission, I began, August 27, 1897, collating the data of the Maritime Canal Company. The note books, maps and other records had been left in a much confused state and deposited in various places. These were all collected in the office of the company at No. 56 Broad street, New York city. Data were transferred to the Commissioner's office at the Army building in Whitehall street, as required, and such details explained and information given as previous experience made available. Some studies were made of prospective routes for survey. Copies of information, necessary for reference in Nicaragua, were made. Maps and selected data were packed and the expedition sailed the morning of December 5 from the Brooklyn Navy Yard on the U. S. Gunboat "Newport." We arrived at Key West December 11 and at Greytown December 17.

December 10 the chief engineer instructed me to make an investigation of the possibilities for an embankment line with a dam across the San Juan river at Tambor Grande.

On my arrival at Greytown, Admiral Walker instructed me to go ashore at once and to investigate the condition of the Maritime Company's buildings with a view to using them as quarters for the expedition and if found favorable to make the necessary arrangements. Accompanied by Messrs. Trundle, Conolly and Lee, I went by the ship's boat to the Atlas steamer "Alene" and from her to the Navigation Company's tug "Rosita," which transferred us to the launch "Miria" lying inside Harbor Head lagoon. The "Miria" attempted to take us to the Greytown wharf, but after a breakdown and much delay we availed ourselves of the use of a twenty-foot steel canoe brought out by Mr. Barnard of the Commissary Department, and paddled to our destination. Mr. Trundle and I walked out to La Fé and looked over the buildings as thoroughly as possible in the darkness. We found them in a neglected condition, and the floors decayed and unsafe in places. It was decided to make the best of these conditions, as

the accommodations in Greytown were inadequate. There was, however, the disadvantage of being located nearly two miles from the commissary and the business center, with no efficient transportation service; however, this location is healthier and freer from distractions than Greytown. The following morning supplies and the officers' personal equipment were lightered to La Fé. A force of men was employed in cleaning and preparing quarters and kitchen. A number of old iron bedsteads were set up and utilized by passing the side bars through the loops of the canvas cots furnished by the Commission. A ground fire-place was prepared for cooking, as the old broken range was inadequate. The party of engineers was landed at 2 P. M., meals were served, and blankets, pillows, cots, rubber bags and mosquito bars were issued. As the bars and blankets were insufficient, the Commission instructed me to supply the deficiency by purchasing them in Greytown.

Messrs. Saabye, Boltz, Heyle, Elson and Snyder were assigned as assistants for the Tambor Grande work, and the party was designated as "No. 5." These men were employed for several days in the selection and packing of stores. Seven macheteros, a cook and helper were selected from the natives in town. Previous experience has decided for me that these men were far more efficient and tractable than the negroes. On December 27 the river steamer "Hollenbeck" came to La Fé at 8.30 A. M. All baggage and equipment were loaded and we started up the San Juan river at 9.30. The steel canoes were lashed alongside. In addition to "Party No. 5," the members of the west side corps and three observers of the hydrographic party were passengers. The steamer arrived at Tambor Grande at 1 A. M., December 28. The supplies were unloaded on the Costa Rican side of the river opposite Tambor Grande point during a severe rainstorm, and the steamer continued her trip. An effort was made to spread a canvas tarpaulin, but the denseness of the jungle and the severe rainfall detracted much from the zeal of the men, so that our shelter was but a partial success. At daybreak a spot was selected for a camp a short distance upstream, where a partial clearing existed. The laborers were instructed to clear a space for the camp and prepare timbers and leaves for shack building. A kitchen was built first and meals served. The tarpaulin was stretched for the officers' quarters, and a palm-leaf shack built for the men. These buildings are quite interesting from the fact that no nails are used, or framing done in any but the most primitive manner. The jungle furnishes all the material. Usually palm leaves are used in thatching and give greater permanency and a better waterproof structure than the wild plantain, which is sometimes used in an emergency. Crotched uprights are first planted firmly in the ground to support the center ridge pole, and then for the wall plates. Usually the sides are not thatched except in the more pretentious structures. All joints are made secure with a liberal use of vines ("bejuca"). Small poles placed parallel to the ridge pole at suitable interval for the leaves, usually less than a foot, are lashed to rafters, and the thatching begins at the lower part of the roof. Three or four leaves on top of each other are placed on the poles so that their stems catch the one above for each longitudinal layer. The layers overlap each other like shingles and make a covering impervious to rain and usually last with little repair for a year or more. On top of the thatching, breaking over the ridge, are placed long branches of the "Silico" palm for binding. The leaves of the

wild plantain are subject to the ravages of worms that destroy them quite rapidly. Our kitchen was quite simple in the furnishing: a ground fire-place with backlog was used, with uprights of crotched poles and cross pole for hanging the kettles. A "Dutch oven" was used for baking. The officers' beds were made by slinging the hammocks on two poles and then supporting them on crotched stakes at the four corners. Spreaders were necessary at both ends. The laborers usually contented themselves with cutting long slats from the palms and making a raised cot, or table, with these supported on crotched stakes.

Other necessary work was the construction of walks made with halved logs, and the building of closets. A wharf and steps had to be built on account of the high bank. The time spent on the camp was about one and a half days for the laborers. The officers in the meantime were employed adjusting instruments and looking up points and bench marks of the former surveys in 1888. The evidences of this survey were apparently obliterated, but after several trial lines, a copper bolt was found in a gavilan tree overgrown with about nine inches of wood. This was at station 120 + 20 of the canal line located by party No. 3, Garnett Savage, engineer in charge under the direction of Lieut. R. E. Peary, sub-chief engineer, A. G. Menocal, chief engineer. The elevation of this B. M. is 104.30 referred to the Canal Company's datum at Greytown, and is subject to the corrections obtained by the precise levels for elevations in the San Francisco basin. This is approximately .025 feet plus the difference of the two data; the Canal Company's and Commission's. The party was furnished with a Brandis transit, 5½-inch plate with a vernier reading to 20 seconds, 3½-inch magnetic needle, 8-inch telescope with 30 seconds bubble, inverting lenses, and stadia hairs with an interval of 1 foot at 100 feet. The graduations of the circle were numbered continuously to 360 degrees and read with a single vernier. The level was Brandis make, with 10 seconds bubble and with stadia hairs. The compass was Gurley make with 5-inch needle and alidade sights. In addition to these there were a Philadelphia level rod, hand level, 100-ft. chain, 100-ft. steel tape, 50-ft. Chesterman tape, transit poles, draughting instruments, etc. The instruments all proved of excellent workmanship and gave most satisfactory results for the character of work desired. It was decided that a compass survey with levels would give the desired results. This survey was started at the old bench mark. The party was provisionally organized with myself at compass, Mr. Elson assistant, Mr. Saabye leveller, Mr. Boltz rodman and Messrs. Heyle and Snyder chainmen. Five macheteros were used with the compass party and two with the level. This constitutes a minimum laborers' force for a party to do effective work. Some time was necessary to familiarize both officers and laborers with their new duties. In general it would seem best to have experienced men, but yet there is some advantage in training men to one's own methods if they are intelligent and ambitious. The survey line followed the crest of the ridge to the San Juan river, and the crossing was made by stadia measurement, in line with the nearest buttress hill. This at first was taken above the point and the embankment would be at an angle upstream, but later this was changed to a line crossing to a hill below Tambor Grande point, which gave better results. The survey from the river proceeded along a narrow ridge, very crooked and broken by saddles. It was at times very difficult to pick out the true ridge among the many spurs. Usually

this was done most successfully by thorough scouting, ahead of the instrument work. This required an examination of both sides of the ridge and a careful consideration of the drainage. The latter feature was very confusing in the neighborhood of the lagoons and easily led to false conclusions. The tropical jungle is so dense, and in places interlaced with vines as to require the use of a machete continuously.

The view obtained usually does not extend beyond the path cut out. It had been suggested by the chief engineer that an effective aid to a general knowledge of the topography could be obtained by observations from high trees on commanding points. Climbers had been provided, and several trees were ascended and sketches were used in directing the survey, but the method was not entirely successful. Usually the view was much obstructed, and inferences could not be entirely reliable, as the peculiarities of the tropical growth almost obliterate differences of elevations of fifty feet. It seems that in general the high trees grow in the flats and the lower ones on the hills. There is great danger in climbing trees in the tropics, especially in the rainy season. The trunk and limbs are very slimy and covered with vines that must be cut away with a machete. Then there is danger of stings from the alligator ants and other insects, and the bites of snakes and the toboba scorpion which are fatal to life. The scouting required great physical effort for the tropics, but, when well done, directed the survey of the ridge with great certainty and with the least work and therefore least expense. It also had the advantage of actually locating the necessary embankments. This work was usually done by the chief of party alone, and the survey directed by sound signals without seeing the party all day. It has been suggested and tried by some engineers, to make a topographical map of the country, cutting it up in squares with survey lines, and pick out the ridge or other features desired, and locate from the map. This may be effective but only with great expense and loss of time. In tree climbing the ordinary lineman's climbers were used. A loose rope was placed around the tree and the body at the loins; then with care a person can walk up the tree cutting the vines as he goes. However, the spurs did not enter the wood of the preferable trees for a view, as the almendro. It was intended at first to trace the embankment line along the divide of Tamborcito and Cureño creeks. The former stream had been unknown previous to the survey, and its large drainage system lying across the desired line of progress was a very disappointing surprise and furnished serious features for the desired embankment line. All efforts to use the divide of Cureño and Tamborcito creeks were without satisfactory results. The elevations of the hills are small, and the ridge is often broken to the swamp level by arms of Tamborcito lagoon. Evidently, as in many other cases, the true divide is the bank of the San Juan river, for quite a distance from Tambor Grande. After recognizing the futility of further surveys up this divide, it was decided to follow the hills that led to Tamborcito creek and cross to the southern side which was unexplored. However an attempt was made to cross an arm of the lagoon and continue the survey, but with unsatisfactory results. A crossing was then located at the outlet of Tamborcito lagoon and a revision of the line made back to the San Juan river ending at the hill mentioned as below the point. This line had greater elevations, is shorter and in many ways more favorable than the first. The two ridges are separated by a flat with small drainage. The San

Juan river crossing seemed very favorable, as soft rock was in sight at both banks, and the distance less than any place on the river, previously exploited for a dam site. The crossing of the valley of Tamborcito creek was recognized as a serious feature, but was the only alternative after the result against the Tamborcito-Cureño divide. The hills after making the crossing proved to be spurs of the Tamborcito-Copalchi divide. This was much broken by the proximity of the lagoons of both these drainage systems. These lagoons are typical of the country. In the wet season they are lakes of considerable extent, and boats can be used, but as the dry season approaches the navigable channel is a mere brook and is often clogged by a rank growth of grass. At such times the lagoons are practically impassable for swimming, wading or boating. It is dangerous to attempt the former. A mattress of grass forms below water level which often sustains a man's weight. The danger is in breaking through into deep water, getting tangled in the grass and drowning. The "manatee" (sea-cow) makes the grassy banks its feeding ground and is quite abundant. The main body of the lagoon is usually not large, but from it radiate arms in all directions. The valley floor at Tamborcito creek crossing is about 3000 feet wide. As the survey up the Tamborcito-Copalchi divide proceeded, it became evident that its use for an embankment line at an elevation above 110 ft. would be of doubtful value. The results were reported to the first assistant engineer on his arrival at camp, January 20, and to the chief engineer on his arrival, January 22. The ridge survey had progressed about 5½ miles, with the adjacent country fairly developed as to all possibilities. It was decided to discontinue the survey, and instructions were given to begin a survey of the San Juan river as soon as the work in progress could be closed advantageously. This required the completion of the leveling which had fallen behind, the taking of some topographic sketches, and the completion of maps, profiles and report. The interval from January 22 to 27 was employed in this work and preparing for the river survey. The general directions for the river survey were; to begin at the mouth of the San Francisco and work down the stream; lines of soundings to be taken at about 1000 feet or less interval; the topography to be roughly determined at occasional intervals by paced compass lines, etc. It was suggested that a system of triangulation be used. As we had only one 20-ft. and one 15-ft. steel canoe, which were not sufficient for our work, it was decided to build a cedar dugout. A trip to Greytown for tools and supplies was necessary. This canoe was made by the party at odd intervals, and proved very valuable throughout all the work. This kind of canoe is easily handled by the men and can be made very light. It cannot replace the steel canoes for rough service and capacity but is always obtainable. A suitable tree, the "ceiba" or "cedro real," is selected near the river bank and felled. This is roughly shaped with axes and adze according to the desired lines, and dressed to the required thickness. The natives use small auger holes to determine this, and later plug these holes.

On January 27 the river triangulation was started by measuring a base line 1500 feet long in Maineri's pasture in front of the mouth of the Rio San Francisco. The angular work was started from this and proceeded down the stream. It was early discovered that the necessary clearing would be a serious delay to progress, and that the assistants assigned for reconnaissance work were unfamiliar with the nicety of work geodetic in character. Usually

the transit points selected were in soft ground near the water and piles had to be used. The triangles were usually ill conditioned on account of obstructions to view, and all angles could not, at times, be measured with facility. Wherever it was possible to check, the angular error was less than one minute for the triangles. The error in distance was less than five feet as checked by the stadia after two miles of survey. The soundings were made on straight lines across the river and located by the stadia. A pole was used for soundings up to 15 feet depth of water and at greater depths, a lead line. The station signals used were the ordinary transit poles guyed in place. The elevations were carried along with the wye level, the observer using transit and level alternately. This method was adopted as best fitted to the organization of the party and its equipment, rather than the usual one of stadia work, and of sounding located by sextant angles. For the stadia work 16-ft. boards had been obtained from Greytown, and were painted and graduated to tenths of a foot. An observer could obtain the distance to the nearest foot from these with great certainty and facility. The work progressed much faster and the assistants were better acquainted with their duties after the end of the triangulation near Tambor Grande point. With the first high water it was found that many transit points were destroyed by the driftwood and falling banks. This gave much trouble, as these points were necessary in other work. The topography work was carried along with the river survey. Assistants were detailed for the scout lines about each half mile. The usual procedure was to go back from the river about a mile, and then make a look back to a lower point downstream and tie up to the river survey. These lines were usually directed to develop some prominent feature of the landscape, and were omitted in the flat, marshy section.

January 27 the steamer "Hollenbeck" came down the river with the Chicago contractors who were studying the canal route. They stopped at our camp during the evening, and by the instructions of the Commission, were allowed the use of results of the survey. The steamer left early the following morning for Ochoa, where the party began their trip across country to Greytown.

Mr. Elson went to Greytown February 6 for an operation on his hand, and returned the 9th. Mr. Saabye was detailed to report to Assistant Engineer Walker, February 9 by instructions from the chief engineer and left for Greytown on the "Hollenbeck."

February 15 camp was moved to a point on the Costa Rican side of the San Juan river about one-quarter mile below the mouth of the Rio Sarapiqui; shacks had been built a few days previously. This location is the site of the old fort at which Walker's filibusters were massacred by the Costa Ricans. The mosquitoes tried to emulate them in attacks on the members of our party and their lack of success was not due to failure of intent or energy. The steamer "Hollenbeck" came down at 5 P. M., shortly after arrival at camp, with orders from the Commission to report at Ochoa as soon as possible with all my laborers to assist in the trip across country to Greytown. We left at 5.30 and made the twenty miles to Ochoa at 3 A. M. after stopping at Maineri's to arrange for men and provisions. February 16 was spent with the Commission in an examination of the dam sites and vicinity of Ochoa. Preparations were made for starting the next morning. Ten laborers, sent by Maineri evidently came by liquid persuasion and were correspondingly noisy and caused consider-

able trouble. It was decided to send all the bulky articles by boat down the San Juan and up the Danta. Our blankets, a few cooking utensils and some provisions were made into packs of about 60 lbs., for each laborer early in the morning. As fast as packs were ready the men were started over the telegraph picket which follows the embankment ridge. Arrangements were made, if necessary to go but half way to Florida lagoon at Camp Escarse, but on arrival there about midday, it was decided to continue our walk and we arrived at the lagoon about 3 P. M., a distance of about six miles. Assistant Engineer Miller and Mr. Lincoln, *Herald* correspondent, joined us in the afternoon. Mr. O'Reardon of the geological party acted as rear guard, and kept the straggler with the packs moving. Our boats could not come up the Danta on account of low water but joined us later at the San Francisco crossing. The camps used by the Commission had been located at intervals of about three miles, or a place requiring difficult engineering constructions.

February 18 the trip was made to the San Francisco river, the Commission making examinations of the various proposed embankments. Upon our arrival at 3.30 P. M., Assistant Engineer F. P. Davis met us with his steel boat and negro laborers. Mr. Maineri also arrived with his boat and some necessary supplies. February 19 the trip was made to Camp Carmen on the Limpio, arriving at 10.30 A. M. and it was decided to camp for the night. This is at the western end of the Eastern Divide. On the 20th the Eastern Divide was inspected and we camped at the Saltos Luisa on the Deseado river. On the 21st, the party followed approximately the canal line to Camp Warner Miller, inspecting the dam site for Lock No. 3 on the way. At the camp there was a short rest, and some of the party walked ahead to Camp Broncho and took the boat that Assistant Engineer Trundle brought up from Camp Menocal. General Hains, myself and three of my macheteros took a boat from Camp Warner Miller to Menocal, inspecting the canal location as it followed the general course of the stream. The river was very low and with many fallen trees, across which the boat had to be lifted, but we made the trip in an hour and a half in spite of all predictions to the contrary. After dinner, on the arrival of the rest of the party, the Commissioners and myself continued on down the river inspecting the canal line and the sites of Locks Nos. 2 and 1. At the latter place we left the boat and took the hand-car to Greytown arriving there at 6 P. M. Our baggage was transferred to La Fé by boat and we crossed the ferry and went by car to headquarters out on the beach. The next two days were spent in getting men, supplies and rewriting my report on the Tambor Grande survey. The latter was submitted to the chief engineer, together with the map and profile. February 24, I started for Camp Sarapiqui, after experiencing much difficulty in getting the men away from the allurements of Greytown. We met Messrs. Boltz and Elson on their way to Greytown in a canoe; the latter had a badly swollen knee requiring the doctor's care. I sent a native in the boat with him and took Mr. Boltz with us. We stopped at Colorado Junction for the night and got to camp at 3 P. M. The officers left at Camp had not been able to accomplish very much during my absence as no laborers were available. Monday, February 28, we continued the river survey and finished to the Cuellos islands at noon, March 5. During this time Messrs. Boltz, Heyle and Snyder were my only assistants. Mr. Carmichael and Mr. Elson reported March 8 and Mr. Heyle started for

Greytown on his way home. In accordance with instruction the river survey was abandoned and preparations made to resume the Tambor Grande embankment survey. To do this required moving our camp inland from the San Juan river, and this could best be done by using Copalchi creek. An investigation proved that this creek was impassable from fallen trees. As it was impossible to pack our equipment to the desired location it became necessary to clear the creek. As this had probably never been done, the work was very difficult and took the entire force of laborers a week. The men worked in the water continually during this time. Usually all that could be done was to saw or cut out a place large enough to pass the boat. Trees like the almendro cannot be cut with an axe and here the saws issued by the Commission were invaluable. Though this delay was much regretted, the time was spent profitably in copying notes, making a map and finishing reconnaissance work. On April 14 we began moving camp to the head of navigation on Copalchi creek, about four miles beyond the end of our work. This moving was very difficult as the creek was getting lower, and trees that had been made passable now gave much trouble. At places the boats had to be unloaded and lifted over the obstructions. It took three days of very exhausting work in the water to get the camp equipment moved, and in this officers and men participated alike. The camp on the Copalchi was very pleasant and well located for our work, but communication with it was difficult. The water was exceptionally pure, and fish and game abundant. March 18 we continued the survey of the Tamborcito-Copalchi divide. At first this was somewhat difficult to trace in the vicinity of the lagoon, on account of the many spurs overlapping each other, and on account of the long narrow branches of swamp. The divide was much broken, but yet advantageous for an embankment. By thorough scouting the divide was picked out and then surveyed and leveled by the assistants. As we got away from the lagoons the divide became more decided and favorable for the embankment project, the average elevation increased slowly, but the breaks in the hills below 110 feet elevation were few and narrow. The distance made per day was 8000 to 10,000 feet. March 23, in an effort to do extra work the party stayed too late in the field. In taking a short cut for camp through unknown country we were confronted with impassable swamps and compelled to wait until morning. Excepting the hunger this experience was not unpleasant. As the ridge had not reached the foot-hills of the Costa Rican range when the walk became too long, it became necessary to build a camp and pack to it. This camp was located at a bend of Caño Tamborcito which was on the north side of the ridge, but was seen first at this place since leaving the lagoon. The camp was made for temporary use only, and occupied by the compass party and later by the level party. The weather was becoming very dry, and ticks of various sizes made life correspondingly miserable both day and night. It was thought that the necessary work could be done from this camp, but on obtaining the results of the levels, which were some days behind, it was decided to push the work farther and another camp was built at the end of the line. We used the camp on Copalchi as a base and packed only necessities out to these camps, but the work was very arduous for officers and laborers. Mr. Elson decided to resign before moving to the last camp and left from Copalchi camp when Mr. Miller came, April 11. Mr. Snyder left on account of sickness March 28 and

Mr. Webb reported to replace him April 6. April 12 the party finished the compass work as far as seemed necessary and all low places in the ridge were cross sectioned. Lines from 200 to 300 feet long were run so as to locate the contours for an accurate estimate. April 17, having completed all work from camp at Copalchi, the men were instructed to move camp to Tambor Grande. Mr. Carmichael and I went to Greytown with a small canoe and one native to transact certain business and make some necessary arrangements for a survey of a proposed canal location along the left bank of the San Juan river. We made the distance to Greytown, about fifty miles, in twelve hours' paddling. The work of such a trip is severe, but the cramped position in a small dug-out in a boiling sun is more trying. On the 27th I started upstream in the small dug-out with my native and arrived at Colorado junction about 6 P. M., passing Lieut. Hanus and his party on their way to the States. At Anderson's we met the chief engineer and Mr. Carmichael, who had started the previous day and were waiting for the river steamer. The steamer "Vero" was lying at the junction and we stayed on her for the night. Finding she might not sail for several days I left in the morning and got to Tambor Grande about 5 o'clock in the afternoon. The men had just finished moving camp and were repairing the shacks. Mr. Carmichael arrived on the "Vero" April 23. On the 25th the party continued the check level and cross-section work. The chief engineer called at camp on the 27th and Mr. Carmichael left for Greytown with him. The officers of the party were now reduced to Mr. Boltz and myself, and finally he had to go to Greytown for hospital treatment, May 1. A large lump formed under one arm attended with high fever. Mr. Anschutz reported for work April 30, but was unacclimated and was unable to stand the long walks for some time. Mr. Carmichael and Mr. Thomas reported May 2, and the work of the embankment survey was finished two days later. The party began the canal location indicated on the map sent with the instructions, by starting at Tambor Grande and running northwest along the left bank of the San Juan river as far as the San Francisco hills. This was followed by another location farther in from the river bank. The curves and tangents were accurately located on the ground.

Progress in such work is very slow owing to the necessity of directing the line cutting with the transit, and of cutting or offsetting for trees. Progress is also materially affected by the length and difficulties of the walks. At first we had insufficient men for both transit and level work. Mr. Carmichael went to Greytown ill with fever May 11. Mr. Thomas and I were the only officers available for field work. This made progress slow, and the use of laborers in responsible positions necessitated continued watchfulness and was discouraging. Mr. Thomas acted as transitman and myself as chainman, axeman, flagman, etc., as the occasion required. We stayed in camp from May 12 to 18, as we did not have enough men for field work. This time was spent in copying notes, making maps and profiles. May 18, having hired more laborers, we resumed the field work of location. On the 23rd Mr. Anschutz was able to do field work and acted as leveller. Mr. Humphrey and Mr. Durham reported next day and were assigned to cross section the survey line. Mr. Boltz returned from Greytown May 28 anxious to work but was not entirely well. Messrs. Seymour and Post reported June 2 and were assigned as leveller and rodman. June 7 we finished all work convenient to Tambor

Grande and moved to Sarapiqui. Our old camp was remodeled to consist of two large shacks, a cook shack and tarpaulin tent. The location survey was continued, and it was noticed not to fit the ground very well and was departing gradually from the desired topography. June 11 men were sent to begin camp building at Punta Petaca at San Juanillo junction on the Nicaragua side. Mr. Hughes and Mr. A. P. Davis called on their way to Greytown and stopped over night. June 19 the steamer "Adele" came down with laborers that were much needed by the engineer parties. The recruiting of men for the war had taken all available laborers from our vicinity. The few men we had were in constant fear of conscription and could not be persuaded to go out to the steamers when soldiers were aboard. This accounted for building our camps on the Costa Rican side of the river previous to the ending of the war. June 21 we moved camp to Punta Petaca. The survey work done from this camp was very disagreeable and difficult to get at. The line follows the general direction of the Rio Negro valley, and this has many difficult lagoon and stream crossings. The walks to and from work were very long and exhausting. Usually the line was run ahead a half or three-quarters of a mile each day, and at evening a trail was cut direct to the river. The floods in the valley made swimming necessary, this was at times dangerous. Several men were swept away and only rescued with great efforts by the better swimmers. The results of the survey showed the line was becoming undesirable for a canal location, although continued as indicated on the map until July 2, when it seemed best to discontinue the survey until further instructions. This was reported to the chief engineer July 3; it was decided to follow the desired line on the ground as closely as possible with a random transit line. A width of topography of 600 feet was taken on the line run, and fitted the old work very well. The surveys of the Rio Negro section made by the Canal Company were very complete in detail and reliable. Our survey from the Rio Negro crossing, followed the left bank of the San Juanillo to the mouth of the Rio Pescado. Mr. Anschutz resigned July 4 and Mr. Thomas was detailed to assist Mr. Evans. Mr. Post was made leveller while Mr. Seymour assisted the transit party. Mr. Humphrey acted as transitman from the Rio Negro to Greytown. July 14 we moved to a camp built at the Rio Pescado. The line leaves the San Juanillo at this point and cuts across a small divide to the Rio Misterioso and follows the right bank of this stream. July 20 we built a new camp on the Misterioso at the head of the lagoon. The transit party moved to this camp, packing such things as were absolutely necessary. The level party continued their work from the old camp. When the line reached Misterioso lagoon it was impossible to cross without boats. As the point of outlet of the Misterioso was unknown, we built a canvas boat and Mr. Seymour and one man made the trip to the San Juanillo, while Mr. Durham and I took the camp equipments around the San Juanillo and met them. The country here is one vast swamp at ordinary stages of the water and the course of the Misterioso was very difficult to follow. A camping ground had been selected and our loaded boats were sent to this site. Mr. Seymour and I went to Greytown for supplies and were picked up by the steamer "Miria" coming out of Silico lake. The Misterioso enters the Rio San Juanillo about three-quarters of a mile above the outlet of Silico lake, but cannot be easily found. As our canvas boat had proved

very useful for the swamp work it was decided to build another better one, and material was procured. The steamer "Miria" took ourselves and supplies as far as Caño Profundo, and we paddled up the Misterioso to the camp built by Mr. Durham. The next morning we continued the transit survey after taking provisions to the level party. The line took us through the center of Misterioso lagoon and then cut across a long bend of the stream along a line of small hills. From the last crossing of the Misterioso to the San Juanillo crossing there is a swampy flat with a depth of water up to six feet, changing with the floods in the river, which has no well-defined banks. After the San Juanillo crossing, it becomes necessary to make a junction with the end of Martinez's survey, and I went to Greytown and cut out his line produced, while the rest of the party continued the survey. We used our firearms for signalling, and effected a junction thereby without any loss of distance. The country back of Greytown is one big swamp grown up with tres, and had depths of water up to eight feet. As the rains were quite severe it was difficult to determine where the water level was with regard to ourselves. We finished the transit work August 4 and the level party came in four days later. The party disbanded as it came in, all equipment was turned over to the commissary and the laborers were paid off. Messrs. Humphrey and Durham checked and copied the transit notes and assisted with the map. Messrs. Post and Boltz checked and copied the level notes. This work was finished August 15, except inking the map, for which Mr. Durham was retained, and the other officers were given assignments by the chief engineer. I was instructed to report to the President of the Commission in Washington, and left Greytown August 19 on the Atlas steamer, arriving at New York August 29. The chief engineer assigned me office work for the estimate and report of the Tambor Grande embankment line. Admiral Walker sent me to New York city October 12 to collect and ship all Maritime Company's data. This was completed October 25, and on my return to Washington the Tambor Grande estimate was abandoned, and an estimate of the San Juan river section made for several variants. Other work up to the present time has been an estimate and report for the Maritime Canal Company's project with the Commission's revised data, a revised estimate of the Commission's Menocal route project, a report and estimate on the Ochoa dam and its construction, an estimate and report on a lock, 15.8 foot lift, etc. All of which work has been submitted, together with maps, note books and data of all field work.

The Tambor Grande Survey.

The information that suggested this survey was the result of a reconnaissance in the year 1893, made when assistant engineer for the Nicaragua Canal Construction Company. It was thought that all possibilities for an embankment across the San Juan valley had been exhausted, but the results obtained seemed to indicate that the investigation at this point might not have been thorough. With a high-level project, using the location across the Eastern Divide, an embankment line below the mouth of the Rio San Francisco is most desirable, as eliminating an embankment line roughly parallel to the river for over fourteen miles. Many of these embankments were manifestly difficult of construction. It seemed that an embankment crossing the valley at right angles should give the best results. Also the material from the divide cut would be available at Tambor

Grande with least work, this would aid greatly in time and cost. The cost of a canal could be materially decreased by bringing the location down the valley of the Chanchos, after leaving the divide. These items, which might decrease greatly the cost, facilitate the construction, and affect the permanency of a canal were the incentives for an investigation. It was at once evident on examination that an embankment line at three of the spurs from the divide, Tamborcito, Sarapiqui and San Francisco would be apparently out of the question, as no continuous hills existed in Costa Rica. At Tambor Grande the spur comes down to the river on the Nicaragua side with no embankments for the highest proposed elevation of the summit level. The developments of the survey in Costa Rica would seem to indicate that a summit level 110 feet would be too great for the topographical conditions. All hopes as to the usefulness of the Cureño-Tamborcito divide were quickly dispelled. The only apparent alternative was to cross the Tamborcito and take the divide between it and the Copalchi. This crossing proved a most serious feature for the project. The divide after this crossing, is apparently useful for an embankment. The geological data as developed by borings show the soil overlying the rock to be clay. The rock in the hills is of two general classes according to the hardness, as found in nearly all investigations in this section. There is the hard rock in place of volcanic origin, and overlying this is the softer rock. The rock in the buttressing hills at Tambor Grande, evident to the observer, is the softer class. This would offer good facilities for the dam construction, were it not for the fact that it is eroded to a depth that would seem inadvisable for dam construction, unless we admit the permanency of rock-fill construction for such cases. This would solve the difficulties at both the river and lagoon crossing, and the entire prism of excavation of the divide cut could be used for this purpose. As a masonry construction the Croton Aqueduct dam has about the same height, but the volume of water to be controlled during the construction is insignificant compared with the floods of the San Juan river. It might be possible to divert the San Juan and build the dam, but it would scarcely seem advisable unless it was an only resort. It is evident from the results obtained showing the rock erosion in the old river bed, that any dam project below the mouth of the San Carlos would be extremely hazardous. Had this knowledge of the old river been available, it would have obviated the necessity for a survey. Another decisive feature developed by the Commission is the danger from the immense sand deposits brought down by the Rio San Carlos. This is a serious danger to any basin project below its mouth. The length of a crest line for the embankments at 118 feet level would be about 8.2 miles. Many of these are small, as the water line, 110 feet level, is but 5.6 miles. With an embankment crest at 98 feet and water level at 90 feet, the crest line would be 3.33 miles and flowage 2.22 miles. This is the scheme that would be most favorable, having a lock at Machuca and making about 20 feet deeper cut at the Divide. It can perhaps be utilized best with a dam above the Rio San Carlos, thus avoiding the sand flow.

San Juan River Survey.

As stated above, it is doubtful if it is expedient to canalize the river below Boca San Carlos on account of the sand, the difficult foundations for the dams and the great volume of water to be controlled during the construction and operation of the canal. These items would seem

to render doubtful the feasibility and permanency of projects involving them.

The Lull Route, Variant I, Survey.

This survey followed the left bank of the San Juan river from the San Francisco to Tamborcito, and then through the valley of the Rio Negro to the San Juanillo, and down the general course of this stream in an almost straight line to Greytown, passing north of the hills around Silico lake. The survey location cut through the spurs at Tambor Grande, Tamborcito and Sarapiqui in a direct line. This alignment is at the cost of extra work that can be partially avoided by more curves, bringing the line nearer the river bank.

The drainage systems on this side of the river are small and can be easily taken care of by weirs. The streams carry little detritus and could be taken into the canal with small expense for dredging during operation, but it would be possible to use invert siphons under the canal entirely doing away with this difficulty. These constructions are troublesome to keep clean. It will be necessary to carefully provide for the action of the great floods which in this section have a wide range and overflow the flats in the Rio Negro valley about eight feet, at the extreme high water. The material in the hills is generally red clay overlying a rock core. The flats are of alluvium overlying clay, excepting in the delta formation which is built almost entirely of black sand.

The line north of Silico lake offers good topographical and geological features for the canal and its locks. The excavation can be done with great facility by dredging except in the large hills.

Lock sites can be so selected as to have rock foundations. It seems probable that this line would give a short line to Greytown with least cost, and of assured permanency. All drainage below the Rio Negro can be shut out of the canal by diversions channels and dams.

If it is considered best to locate a harbor near Rio Indio, in order to avoid the sand from the Rio Colorado as much as possible, this location would be most available for a low-level project.

Regarding the character of the survey work it was found, that in a loop of the canal location and river survey from the Rio San Francisco to Tamborcito, a circuit of about eight miles, the closure error was about thirty feet. In plotting our location in connection with the Lull survey the results at Greytown checked with great nicety.

The facilities of transportation are very limited. The rivers are usually in a chronic state of low water, or are clogged with trees. During the work of the Canal Company, snag boats were used in the Rio Deseado, San Francisco, Danta, San Juanillo and others. Usually a twenty-foot canoe is the largest craft that can be used on these streams for transportation. The railway as constructed was invaluable and is a necessary adjunct of canal construction. The country offers very little for construction work. Quarries are as yet undeveloped. Good stone is very scarce. Usually soft rock overlies the better grades for considerable depth so that they are not easily available. If the Eastern Divide cut is made, its material would be useful, otherwise rock must be quarried for lock masonry, etc. For this the sandstone at Machuca seems most available and it can be obtained in large blocks. Stone of a better grade can be obtained from the west side of the lake where good quarries exist.

Timber for construction has been undeveloped. The forests are not deciduous, and the

trees have much sap that causes rapid decay. It seems that the flow of sap is affected by phases of the moon and this has a great influence on their decay. The natives recognize this and cut their trees accordingly. The better grades of timber when seasoned give good results. The timber should be felled or girdled when the least sap is in the trunks. A strange feature of the tropical forest is that trees of all kinds grow together promiscuously. There are no forests of any one kind like our pine woods. Trees like the mahogany are scattered often at a mile or more apart.

For railway construction the cutarro and nispero give good results for ties. Many trees would give good results in foundations and some in superstructure. Of the latter are the cedars, manwood, nispero, blackwood, etc., which are fairly abundant. The Cuban pine growing in the Prinzapolka district gives good lumber. There are no sawmills in the San Juan valley at present, and timber is difficult to get at, except near the river banks. No doubt lumbermen could readily overcome this difficulty. The white ants honeycomb and destroy timber very rapidly. Some timber is not affected by these pests; such as the cedro real. Ties of good native wood, as the nispero, last from one to three years and cost about fifty cents silver. Lignum vitæ ties may last, as at Panama, 15 to 30 years, but cost much more and are difficult to obtain.

Regarding the health of the party, due allowance must be made for the fact that we were employed the entire time in the worst section of Nicaragua and engaged on work that was most difficult of attack. The number of officers that became ill was perhaps greater than in any other party, due to this fact. The survey was pushed and the men wore out unless inured to work and hardships. It is true that the influence of life in the swamps for so long a period produced its effects, yet one laborer and myself passed through it all without the slightest sickness, or missing a single day's work.

Immaturity has a great influence on men, and it was a rule with the Canal Company's surgeons, that no one under 21 years of age was considered a proper person for exposure to the enervating effect of the tropics. The party was almost entirely supplied by the rations issued by the commissary, which were very satisfactory. These were supplemented by plantains, game and fish. It was found necessary to decrease the allowance of meat and almost dispense with its use for officers and laborers alike. In place of meat an extra allowance of rice and beans was used. These with plantains should form the bulk of rations in the tropics. The observations of nearly five years in these swamp surveys would seem to indicate that liquor, properly used at times of great physical depression, is a restorative of great value, while the abuse of it is attended with worse effects and more immediate than in the temperate zone.

Much credit is due to the officers and laborers alike for the successful prosecution of the work, exposed to great hardships and very trying difficulties. Each gave his efforts as he could and contributed to the work accomplished, which it is hoped may meet with your commendation and be an aid to the greatest engineering scheme of this century, an Isthmian Canal.

In conclusion I wish to acknowledge my indebtedness to my associates for the measure of success attained, and for favorably seconding my efforts; particularly is mention due to Messrs. Carmichael, Thomas, Post, Boltz, Humphrey and Durham for ability and faithfulness.

APPENDIX VIII

REPORT OF S. S. EVANS

Assistant Engineer

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APPENDIX VIII

WASHINGTON, D. C., April 15, 1898.

MR. E. S. WHEELER, Chief Engineer, Nicaragua Canal Commission.

Sir:—I joined the expedition for Nicaragua in New York, on December 4, 1897, leaving on the next day on the "Newport" for Greytown. On arriving there, December 17, I was assigned as assistant to Mr. George W. Brown on the survey of the Rio San Juan, and on the measurement of a base line at Fort San Carlos for use in the triangulation of Lake Nicaragua. Mr. Brown, being shortly recalled to the States, was replaced by Mr. Francis Lee Stuart, with whom I remained until July 3, 1898, the survey of the San Juan being by this time nearly completed. On July 1, I received orders to report at Greytown for other duties, and on arriving there July 3, was assigned to take charge of a party then engaged in measuring a proposed low-level line from Harbor Head to a point near Punta Petaca, passing south of Lake Silico. This work was completed August 26, and I received orders to report at Washington in company with others who were to leave Greytown September 2; but on August 31 instructions came from the President of the Commission requiring the presence of Mr. H. C. Miller, the first assistant engineer, in Washington, and detailing me to remain in Greytown acting in his place. On September 27 Mr. A. P. Davis sailed for Washington, leaving me in general charge of the hydrographic work. On December 19 I received orders to make an investigation of a proposed dam site above the mouth of the San Carlos river and to take the topography on the north side of the San Juan from the San Carlos to a point one mile below the Machado creek. This I completed February 4, 1899, and returned to Greytown. After storing the remaining property of the Commission in one of the Maritime Canal Company's buildings at La Fé, and leaving Mr. H. C. Hurd in charge of the hydrographic parties still in the field, I took passage on the Atlas steamer "Alene," on February 18 and reported at the office of the Commission at Washington on March 6, 1899.

I beg to submit the following more detailed report of my work and experiences in Nicaragua while in the service of the Commission, beginning with the date July 4, 1898, when I took charge of the party surveying the low-level line south of Lake Silico. My work previous to that time is covered by the report of Mr. Francis Lee Stuart.

On arrival at the encampment of the party on a small hill near Lake Silico, I found that the line had already been run to station 109+96.6 on the south bank of the river San Juanillo, as shown by the accompanying map. I found also that the San Juan river had recently risen and overflowed the swamps through which the line runs to an average depth of from four to five feet. As it is impossible to work in this depth of water on foot, especially as there were fre-

quent holes in which the water and mud were several feet deeper, it was necessary to do all the work from boats. The instrument could not be set up on its tripod and resort was had to driving a long pile in the mud in the place of the ordinary transit hub. This was made firm by braces, its top cut off square and a board nailed thereon. Into the board the center tack was driven, over which the trivet of the instrument was centered and nailed fast. The instrument was then screwed to the trivet and the line carried forward as ordinarily. The distances were obtained by stadia readings. In this manner an average distance of about one-quarter mile per day was covered for about three miles, when the ground becoming higher and the water having fallen to some extent, we managed to push ahead without the use of the boats. At station 377 we reached the first of the hills which surround Lake Silico. From here the line ran over a succession of steep hills and swampy flats. The flats are all at the level of the fan-shaped delta plain which slopes gradually toward the coast, and the hills have the appearance of being thrust up through it, or of having settled down, the plain having been afterward formed around them by deposition from water. The principal body of the hills crossed is between station 386 and station 572, making about 3.5 miles of hills, the maximum height of which is 170 feet above sea level. From station 572 to the end of the line opposite the upper end of the San Juanillo river the swampy delta plain is again traversed, being broken by occasional small hills. After crossing the San Juanillo the survey was connected to station 18 of the river work by a compass line 5400 feet long.

The Caribbean and Pacific Transit Company are building a line of railway from the head of Lake Silico to a point on the San Juan river. We crossed this line at three points, stations 511+74, 520+54, and 563+35, respectively. The construction of this road has necessitated the excavation of several cuts through the hills, one of which is 40 feet deep. At these cuts some observations can be made on the character of the interior of the hills, and from the experience of the Transit Company, some conclusions can be arrived at as to the difficulties and cost of doing earthwork in this locality.

Physical Features.—The line runs for practically its whole length through the delta plain of the San Juan river, the original topography of which is covered over by the deposits of the river, with the exception of the hills still projecting up through it. The plain is intersected by several open spaces of water or lagoons and numerous watercourses, the principal of which is the San Juanillo river which leaves the San Juan river through a small channel a short distance below Punta Petaca and gathering numerous tributaries, the principal of which are the Rio Deseado, Rio Misterioso and Caño Profundo, by which it is swelled into a considerable stream, again enters the San Juan about two miles from Greytown. Lake Silico is a picturesque body of water about one and a quarter miles long and three-quarters wide, set in among the hills and having the appearance of being a true lake and not a lagoon. It discharges into the San Juanillo by means of the Caño Profundo. The swamps of the delta plain are covered with a deposit more or less thick of loose vegetable matter fallen from trees, palms, etc., to which more or less consistency is given by matted roots. In walking over it there is constant liability of stepping into a soft place and sinking up to the waist or possibly over the head.

The topography of the hill section is very much broken. The hills are composed on the

surface of clay, weathered from volcanic rock which is probably, as found elsewhere in similar hills, from 50 to 80 feet below the surface. The railroad cuts did not show any solid ledge of rock, but the ground was full of large boulders which were broken up by blasting.

Cost of Earth Excavation.—The cost of moving the earth in the railroad cuts was stated to me by Mr. Shardsmith, the engineer in charge, as between forty and fifty cents per cubic yard. None of it was moved more than about 300 feet. The method of doing the work was primitive, it not being of sufficient magnitude to warrant the importation of the proper tools. The only means of transporting the excavated earth was by wheelbarrows, and in case of one of the cuts, by two or three small dump cars, only one of which could be filled at once. The earth was loosened by picks and by powder blasts. At the time I saw it, it was the worst of the rainy season, and the whole place was one grand mud-puddle which of course added to the cost. The labor employed consisted principally of negroes from the Fortune islands, together with some native Nicaraguans. There did not appear to be any more sickness among them than would be expected in a similar gang in the United States.

Vegetation.—The most characteristic vegetable growth of the delta plain, and of all swamps in the region of the San Juan whose elevation does not exceed about two feet below the maximum flood-plane, is the llolio palm. The presence of the palm is a sure indication of swamps of this character. They are called by the Americans "Silico swamps." In parts where the ground is high enough to be only occasionally submerged there is a timber growth, the most useful tree perhaps being the gavilan or wild tamarind. It furnished a hard and very durable wood, suitable for railroad cross-ties and similar purposes. Among the hills there are several varieties of trees whose wood is valuable. Some of these woods, according to the testimony of the natives, seem to resist natural decay almost indefinitely and for strength and durability are far superior to any that could be imported from the States. With the opportunities and sources of information that we had while living in camp, and with the limited time available for making observations on these woods it was impossible to get together anything like precise data. Such information as could be obtained from the native workmen with us, either as to the correct names of the trees or quality of timber to be obtained from them, was too conflicting to be used in formulating any reliable statement of facts concerning them.

Health of the Party.—During the time of the survey the party lived in camp in the midst of the swamps, were almost constantly wet while at work from rain and from wading through the water and mud of the swamps, and the work was fatiguing in the extreme. Yet there was no sickness except some boils among the laborers, and in my own case an abscess on the hand. The line was finished August 26, and as the time allotted for doing the work had expired, no extended topography of the hills was taken as had been intended originally. If this topography were taken there is little doubt that it would reveal a much more economical line through the hills than that actually run over.

On September 1, I was placed in charge of headquarters at Greytown, and my time till my departure from Nicaragua was occupied in attending to all the details of the Commission's affairs in Nicaragua. Among other duties I made monthly rounds of all the camps occupied by the hydrographic parties, inspected their work

and forwarded their monthly reports to Mr. A. P. Davis at Washington. Owing to the slow means of communication of the country, each of these rounds occupied nearly half the month.

On December 4, when about closing up the affairs of the Commission in Greytown, preparatory to leaving for Washington in company with several members of Mr. Stuart's party, I received a telegram from the President of the Commission ordering me to hold all men in Greytown until written instructions should arrive. These came on December 19, and directed me to organize a corps and proceed to take the topography of the country on both sides of the river above the mouth of the San Carlos river, and to make borings to the rock, all with the view of investigating the place as a site for a proposed dam. The topography was to be carried back on both sides of the river along the ridge lines to verify the connection with the interior hills of the country, and also to be carried down along the north side of the San Juan river to a point one mile below the mouth of the Machado creek. Accordingly I made up a party from the few men left me. Two of these were sick; one with an abscess and one with malarial fever. The physician advised me that they had best go to the States to recuperate. There were left only three men. But as Mr. A. P. Davis desired to have two of the gaging stations discontinued, two more were made available, increasing my party to five. One of these, Moriz Bernstein, was detailed to take charge of the borings and supplied himself with one Pierce rig for driving pipe and one diamond drill outfit. There happened to be a large frame house at the junction of the San Carlos with the San Juan and in a location very convenient to the work. This I rented and in it the party was housed very comfortably. We left Greytown in the river steamer on the 27th of December, taking along 20 laborers, 6 for the drilling party and the remainder for the topographers. After some searching we found some of the old river survey stations to which we tied the new work. The map furnished me with my orders showed a proposed canal location through the hills in the bend of the river at Boca San Carlos, and I decided to run a transit line along this location for a basis on which to tie the topography. This transit line was afterward continued down the river to the end of the work. Over this transit line the level was run, starting with the elevation (62.29) taken from station No. 604 of the river survey, and checking up again within one-tenth of a foot on the precise level B. M. at Ochoa. From the transit line various spur lines were run, some with the transit and less important ones with a compass. The ridge lines on both sides of the river were run with the compass. The level was run over the spur lines and over the ridge lines. Then at every 200 feet, both of the main transit lines and of the spur lines, a cross section was taken with compass, hand level and tape, locating each 10-foot contour at distances 200 feet apart. Every foot of all these lines was cut through the brush with machetes and a great deal of the work was done in heavy rains, January having proved to be a very rainy month.

No point of the ridge line on either side of the river was found to be below 110 feet above sea level, except one small saddle on the south side. The length of this opening at the 110-foot level is 500 feet and the lowest point in it is 90 feet above sea level. This depression could be utilized if thought advisable, for the construction of a waste-weir. The ridge seems to be a spur of the west watershed of the Machado creek through which the San Juan has

broken. Within one-half mile of the river on the Costa Rican side it expands into a chain of hills having peaks 1000 feet high and which probably connects with the interior mountain system of Costa Rica.

On the cross section of the river five holes were bored, the first two of which were separate attempts at hole No. 1. In neither of these holes was bed rock reached, owing to the great number of boulders and small stones encountered which choked up the holes whenever the drill was withdrawn. We did not have time enough at our disposal to persevere until this difficulty was overcome. These holes are marked on the accompanying map as hole No. 1-a and No. 1-b. They reached the elevations 73 and 43 above sea level respectively. In hole No. 2 rock was struck at 2 feet above, in hole No. 3 at 15 below, and in No. 4 at 30 feet above sea level. On February 4, this work being completed, the party returned to Greytown. Two of the drill outfits were shipped to the Department of the Interior for use in Arizona, and the remaining ones, together with some boats and other property belonging to the Commission, were stored in one of the buildings of the Maritime Canal Company at La Fé. A list of this property has been handed to the Commission by the store-keeper, Mr. Thomas J. Boltz. The two steam launches used on the hydrographical survey of the lake and river, and belonging to the Navy Department, were stored in the care of the U. S. Consul at Greytown. The care of the hydrographical parties still in the field was turned over to Mr. H. C. Hurd in accordance with orders from the President of the Commission. It was arranged that he should have his headquarters at San Carlos.

The building used for headquarters, and also that for the storehouse, were surrendered to their owners, and on February 18 the party took passage on the Atlas steamer "Alene," arriving in Washington March 6.

The Labor Question and Effects of the Climate of Nicaragua.—During my fifteen months' residence in Nicaragua I had opportunity to observe the character of the labor there used, both of the native Nicaraguans and of the Jamaican negroes. Either the one or the other of these two classes was used in all the camps of the expedition. I noted the experiences of the officers of the Caribbean and Pacific Transit Company as well as of many others with the same classes of men. I think it is the universal testimony of all the assistant engineers to the Commission who had to deal with these laborers, that they are, as a rule, very unsatisfactory. But I do not think that this is due to physical inability to do a good day's work or to the enervating effect of the climate. This latter I believe is a popular fallacy. It is my opinion that we must look deeper than to mere climatic influences to find the true explanation of the want of efficiency of the labor here. It is inherent in the constitution of the races of people who are found in these countries. They simply lack the moral stamina to voluntarily endure any prolonged exertion. The American negroes are generally credited with being much better laborers than those from Jamaica. But, as negro nature is about the same the world over, those from the United States are probably better because they are held up to a higher standard by their environment. The laborers of the countries to the south of us have little training, are entirely irresponsible, and having no ambitions and but few necessities they are not incited to better their condition by incentives felt by people of better races. Consequently they are not inclined to work at all, except as obliged by ne-

cessity, and then only long enough to supply present needs. They seem to work well enough for a short period, but are disinclined to any continued effort. A foreman of one of the railway gangs who had employed them on the Isthmus of Panama, told me that this fact was recognized there, and that it had been his custom to discharge his entire gang at the end of each month, hiring new ones, and taking on the old ones again at the beginning of the following month. Such a system would no doubt require an efficient police service to keep in order the relay of idle men, but perhaps by following some such tactics very good results could be obtained. Certainly something of a special nature will have to be done in treating the problem of labor.

Aid to be Derived from the Resources of Nicaragua.—Some assistance can be derived from an intelligent utilization of the resources of Nicaragua. Unfortunately there is probably no coal, but there is an abundance of timber, some food supplies and some labor. The productiveness of these sources of aid could be expected to increase during the progress of the work, as the demand would lead to development.

Timber Supply.—There are various kinds of timber in Nicaragua which, for strength and durability, it is generally admitted, are far superior to any that would be imported. Leaving out of consideration mahogany, cedar, granadilla, rosewood and such other fine woods which are too valuable for extended use in canal construction, some of the most useful trees are the almendro, cortez, nispera, madera negra, gavilan or wild tamarind, sapodilla, guanacosto, cottonwood—different from that in the United States—and others.

But, with the exception of one concern on the Atlantic coast which is extensively engaged in exporting mahogany, there are no mills nor any one engaged in the business of taking the timber from the forests and preparing it for commercial uses. Such small quantities as are required to supply the native demands are sawed from the log by hand.

Owing to my limited opportunities for observation I could not say whether the various kinds of excellent woods which I saw in use are to be found in sufficient quantities to warrant the establishment of saw mill plants, and, while there is abundance of forest, it seems to be a fact that no one variety of tree grows in bodies or groves, but is scattered over large areas and is interspersed among worthless trees. The denseness of the forest and difficult topography of the hills united to the expense of making roads over the ground usually softened by rains, might make the cost of assembling the logs at mills so great that competition in price per foot B. M. with imported timber would be out of the question.

But at any rate where it is necessary to lay corduroy for supporting railway tracks and other roads, abundance of suitable logs can be had close at hand, and it is also probable that sufficient railway cross-ties of durable wood can be obtained at no greater cost than that of importing inferior ones.

In view of the superior quality of the Nicaraguan timber, it seems to me that in case of further investigation of the canal question it would be profitable to make a thorough examination of the availability of the timber resources of the country and of the probable cost of delivering it at the works ready for use.

Native Food Supply.—There are good pasture lands wherever the timber is cleared away, and cattle appear to thrive. There are extensive grazing lands on the eastern side of the lake from which cattle are annually exported to

Costa Rica. The native market is well supplied with fresh meat. The present cattle production is only limited by the available market. It easily could and probably would develop to meet the needs of the canal laborers for fresh meat. Cheese is also produced in sufficient quantity to meet the needs of the country, and coffee is one of the principal articles of export. Two prime articles of the diet of all laborers here are plantains and beans, and these, with bananas, oranges, limes, pineapples and yams, can be produced in unlimited quantities and at short notice.

Native Labor Supply.—This is quite limited. The Nicaraguan laborer and negro are not easily trained to classes of work with which they are not familiar. They can be used as woodsmen, boatmen, porters and for similar work, but would be nearly useless for heavy labor with pick and shovel and the like. They do well enough for a few weeks, but like all other laborers in these countries cannot be depended upon to remain steadily at work for a prolonged period.

I append hereto an estimate of the probable cost of a rock-filled dam at Boca San Carlos, and of a waste-weir at the same point.

The dam has its crest at elevation 115 above sea level. The rock-fill is 20 feet wide on top and has a slope of $2\frac{1}{2}$ horizontal to 1 vertical on the down stream side and on the upper side a slope of one on one. The upper side is covered with an earth-fill, sloping 3 horizontal to 1 vertical. The rock-fill composing the dam is designed to rest on the hard rock bottom lying under the river bed, the silt having been removed by dredging. The waste-weir is to have its crest at 98 feet above sea level, be built of concrete, be 18 feet thick on top and rest on the rock. It is estimated on the basis that it increases 0.45 feet in thickness for each foot of height. It has a wing wall at each end. It is located in the hill on the south side, its nearest end 1800 feet from the end of the dam. The estimate covers excavation of the hill on the down stream side to the level of the crest of the weir and four feet below the crest on the upstream side. Between the dam and the weir there is a small saddle or depression in the hill, the filling of which with earth to the level, 115, is estimated for. The weir is placed in the higher ground because the rock bottom is supposed to be higher there, thus lessening the quantity of masonry required.

The estimate is probably ample, as the downstream slope on the rock-fill is $2\frac{1}{2}$ to 1, whereas in rock-fill dams already constructed, the slope has usually been 1 on 1 on both sides. The masonry in the weir is also heavy, but this may be necessary to provide for the shock of the great volume of water which will sometimes flow over it. The weir provides for a discharge of 75,000 cubic feet per second, with a head of 8 feet. If a larger capacity is required the extra cost would be about in proportion to the increased length of weir.

Respectfully submitted,

S. S. Evans,
Assistant Engineer.

ESTIMATE OF COST OF ROCK-FILL DAM AND MASONRY WASTE-WEIR AT BOCA SAN CARLOS.

Crest of Dam, 115. Crest of Weir, 98.

	Cu. yds.	At	
Earth excavation for weir	851,926	$0.37	$315,212.62
Soft rock excavation for weir	108,025	93	100,463.25
Masonry for weir	46,748	8.30	388,008.40
Excavation of silt for dam	1,475,090	.37	545,783.30
Rock-fill for dam	1,358,125	1.50	2,027,187.50
Earth for dam	475,541	.37	175,950.17
Earth-fill for small dam, across saddle	23,885	.37	8,837.45
Regulating works, 1200 feet		$266.67	320,004.00
Total			$3,881,446.69

APPENDIX IX

REPORT

ON THE

PRECISE LEVEL LINE

FROM THE

CARIBBEAN SEA TO THE PACIFIC OCEAN

BY

STEPHEN HARRIS

Assistant Engineer

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APPENDIX IX

WASHINGTON, D. C., April 15, 1899.

MR. E. S. WHEELER, Chief Engineer, Nicaragua Canal Commission.

Sir:—The following report of the work done and results obtained by the Precise Level Party under my charge is herewith respectfully submitted.

The work assigned us was to carry two precise level lines along the route of the canal from Greytown, the Atlantic terminus, to Brito, the Pacific terminus, except that connection was to be made across Lake Nicaragua by gages established at San Carlos and at Las Lajas.

Along the route of the canal at suitable places, about five miles apart, benches were to be established with which the ordinary level work could be connected.

The levels and rods used in this work were borrowed from the Engineer Corps, U. S. A. The levels were marked No. 1 and No. 3, and were made by J. Kern of Aarau, Switzerland. The rods were marked X, XIII, XV and XVI. In these levels the bubble rests on top of the rings when in use, and is carried in the hand when the instrument is being moved. A mirror is provided by which the bubble can be read without moving the eye from the eye-piece. There is a screw with a very fine thread under one wye which is used for the final leveling of the telescope when pointed on the rod. There are three leveling screws and a circular or box level for convenience in setting. There are three horizontal wires, and the mean of the three readings is taken.

The leveling rod is made in one piece, three meters long, four inches wide on the face, and strengthened by a piece at the back, making a T-shaped cross section. It is self-reading, graduated to centimeters, and is read by estimation to millimeters. The decimeters are figured on one side of the graduation, and the centimeters on the other. A box level is attached to the rod to enable the rodman to hold it vertical, and this in turn is tested by means of a plumb line.

Before determining any elevations on the canal line, both instruments were carefully examined and their constants determined as accurately as was possible under the existing circumstances. For instrument No. 1 the value of one division on the bubble was found by trial to be 2.91 sec. The bubble was marked 2.85 sec. The value of a division appeared constant for different parts of the bubble-tube.

The telescope rings were found to be as nearly equal as could be determined in the field, the level bubble not showing a variation of more than one division when the telescope was reversed in the wyes.

The object glass did not seem to be perfectly centered, but was not enough out to interfere with the work.

A stadia table was calculated, giving the number of feet equivalent to the space on the rod intercepted between the extreme wires. This

space being 151 mm. at 100 feet. The rests for the striding level were somewhat worn, so that it was necessary to see that it was always placed in the same position on the telescope.

For instrument No. 3, the value of one division on the level was $2\frac{1}{2}$ sec. The telescope rings were found to be practically equal, and the object glass well centered. A stadia table was calculated giving the number of feet equivalent to the number of millimeters on the rod intercepted between the extreme wires, this being 146 millimeters at 100 feet. The rods were examined and found to agree with each other in length, and the attached levels were adjusted so that when the bubble was in the center, the rods were vertical. The rods were provided with foot plates. These could not be used, as much of the country passed over was swamp, and all of it covered by a mass of roots which would have been very hard to remove when placing the plates.

We at first used hard wood turning points $3\frac{1}{2}''$ square and $16''$ long, strengthened with an iron band on top, and having an inch pin sunk in the middle of a two-inch hole in the center of the head. The points were driven with a heavy iron mall, and carried forward with the rods. In the swampy ground we were obliged to drive piles for turning points, and in places for the instrument, using on several occasions, piles $16'$ long. The first turning points lasted to Ochoa, and then we used in their place, $3''$ stakes with ten-penny nails, driven for turning points, not removing the stakes as we went forward. Each morning before commencing work the collimation adjustment, the bubble adjustment, and the rods were examined, and, if necessary, were corrected. The record of these adjustments was written before the record of the day's work.

At Greytown a trial mile was laid off, and both instruments tried twice over the course. Instrument No. 1 closed on the initial point by 3.7 mm. and by 2.3 mm. Instrument No. 3 closed on the initial point by 0.3 mm. and by 4.2 mm.

The organization of the party varied as the work progressed. At first the chief of party was free to watch the work of both instruments, to look over the line ahead, and to attend to moving camp and securing supplies. There was an instrument man and a recorder for each instrument, and a man in camp to copy notes; and it was expected that another American would be assigned to the party to cut line ahead. The rodmen were at first Jamaica negroes who were replaced by Spaniards as soon as we could get them. It was originally intended that there should be seven Americans in the party. This number decreased as we moved toward the Pacific and at Brito there were but four.

The rate of speed of the party varied considerably. The heavy and incessant rain on the east side was a great hindrance, and the hard dashes came right through the carriage umbrellas we used, and soon fogged the glasses. The country up the valley of the Deseado was very much broken and continued bad till we reached the San Juan river at Ochoa. On the Deseado when the rain was moderate and the other conditions favorable, we made half a mile a day. Another source of delay for this part of the line was the time lost in moving camp. Travel was so hard that it was found necessary to keep the camps about five miles apart; and the moving from camp to camp, sometimes by rivers blocked by logs, sometimes packing on men's backs, used up a great deal of time. The labor when the party was not near a source of supply was a serious question. As the wants of the men are few, they need very little money, and they

do not care to work steadily, the average time for a man being about a month. Then the Spaniards, who are very much better and more reliable than the negroes, do not speak English.

From Greytown to Ochoa the average rate of speed was 10 miles a month. As we traveled west the speed of the party increased; we found level ground by holding the river bank; we lost less time moving camp and could keep the camps further apart, and the rainfall decreased. While on the river banks, we in places had to work our way round steep bluffs, and in places were for miles in water up to our waists, sometimes being obliged to drive a short pile under each tripod-leg to keep the top of the tripod above water. Five or six miles below San Carlos, the water at the edge of the river—that is where the grass and trees begin—was from six to twenty feet deep for a mile, and here we were obliged to take longer sights than usual, and zigzag across the river, placing the top of the instrument on cut-off trees, and driving piles for turning points, making the foresights and backsights equal. The longest of these sights was 1112 feet, and the rods could just be read in a favorable light at that distance. The readings were checked by putting rubber bands on the rods, and any large error guarded against by measuring from the turning points to the water at practically one time, and seeing that the water elevations increased regularly for the three long sights. The distance from the first to the second turning point was 2215 feet, and the increase in elevation of the surface of the river was .042 feet. From the second to the third turning point was 1736 feet and the increase in elevation of the river was .036 feet. From the third to the fourth was 1704 feet, and the increase in elevation was .037 feet. The trees did not form a very steady support, as any slight motion of the wind or water was communicated to the instrument, and it was necessary to select a time when the water was calm and the wind had died down. The readings were taken by two observers in a boat which was wedged into the vegetation near the instrument, one observer reading when the other noticed that the bubble had come to a rest. To have gone round this mile of water would have added to our line seven or eight miles of badly broken country and swamp. On the upper river when everything was favorable, we made about a mile a day, and west of the lake, from two to three miles. Our running west of Ochoa varied from ten to twenty-five miles a month.

When we could get plenty of native help, and our party was organized to do its best work, the method of procedure and arrangement of the men was as follows:

The line was first cut out ahead, holding the river bottom wherever practicable, even to the extent of doubling the length of the line. The line was kept as nearly in one direction as possible, but all trees that could not be cut in a few minutes were left standing. This was done by a party consisting of an American and five natives working in the shape of a V. One native going ahead, and two following on each side to widen and clear. In this way about a mile of line could be cut in a day. Sometimes the underbrush was found so heavy and the swamp so hard to force through, that it was necessary to have two parties cutting in order to keep ahead of the instruments.

With the first instrument there were two Americans and seven natives. One American for instrument man and one for recorder, two natives as rodmen, one to furnish and drive turning points, one to carry the instrument, one to carry the umbrella and lunch, and two others

to cut line. A great deal of clearing had to be done by this party, and all the natives were used for that purpose.

The second level party consisted of one American and five natives. The American as instrument man and recorder, two natives as rodmen, one native to carry the instrument, one to carry the umbrella and lunch, and one to cut line and follow with the boat. This party followed the first party using turning points in the same places, as any change would mean clearing a new line.

Besides the three parties mentioned, there was an American in camp copying notes and making arrangements for moving ahead, and a cook and a helper. The entire party then consisted of five Americans and nineteen natives.

As the conditions were such that it was not to be expected that the instrument would hold its adjustment as well as in ordinary work in the United States, great care was exercised to make the foresights and backsights equal, and every precaution taken that the instrument be not disturbed between the reading of the backsight and foresight, so that the slight vertical angle always present might remain constant for that time. We made the sights, when possible, about 200 feet. This is shorter than the usual length of sight, and we at first tried to get 300′ sights. We found this too long for the poor light in the dense forests, and also to require very much more cutting, so that the fastest time was made with 200′ as the maximum length of sight. As part of the country was very badly broken and very steep hillside, our minimum sight was determined by the focusing power of the telescope, and was 15 feet. We averaged in the country near the divide, 50 set-ups to the mile, and along the upper part of the San Juan river, 25 set-ups to the mile. At first we made the sights equal by steel tape measurements, which gave us an additional check on the interval between the wires, but finally we were obliged to rely entirely upon stadia measurements, as the work with the tape took up too much time.

Our method of work was as follows:

After taking a sight the instrument man walked past the foresight, selecting a point for the instrument. The rodman who had been at the backsight advanced counting his steps from the new backsight point to the instrument, and going an equal number beyond. The instrument man read the distance to the new backsight rod, and then set the foresight rod to within a foot of the same distance. The backsight rod was then read and recorded, and then the foresight; and then the backsight again, and the foresight, to check the first readings and see if there had been any marked change in the instrument height. If the readings showed a change, they were discarded, the instrument was made more solid, and an effort made to allow less time to elapse between the readings. At the end of five miles when the party reached a numbered bench, a change in the order of reading would be made; the foresights being read first, so preventing a cumulative error from the changed height of instrument. By reading backsights first with one instrument and foresights first with the other, these small changes could be watched, and we found that on sand or clay, with very little vegetable matter, there was a slight settlement of the instrument—while on the swamps where the ground was just above water level, and wherever there was a mass of roots and vegetable matter reaching below the points of the tripod, the instrument showed a tendency to rise. In the country through which we passed, these two were very nearly equal.

When the readings of the three wires were

recorded, the spaces intercepted on the rod between the center and the outside wires were written down. These intervals should be equal if the wires were evenly spaced. In our instruments they were not evenly spaced and the intervals were not quite equal. If the readings did not show the intervals nearly equal, and one of them a certain fixed percentage of the other, there was an error in the reading, and the rods were re-read. For the calculation of the next elevation, and for a check on the previous work, a third of the sum of the three readings was recorded, and if the work was correct, this would differ from the middle reading by one-third the difference of the intercepted intervals. From the mean backsight and foresight readings, the elevation of the new backsight was figured. The distances and rod numbers for office reduction were recorded, and the party was ready to again advance. It was at first intended to note the distance the bubble was from the center at the time of reading and to make a corresponding reduction. It was found that in the swampy ground and tangle of vines everywhere present on the line, the recorder could not do this work without disturbing the instrument, and that if it were attempted by the instrument man, the increased length of time between the back- and foresights would introduce a greater error than that eliminated by noting the exact position of the bubble; as it could generally be kept within at least a quarter of a division of center while reading.

While there were many petty annoyances from insects, rain and mud, the conditions were almost ideal for good levels. In the dense tropical forest in which we worked there was absolute stillness and the bubble was unusually stable. The whole length of sight was generally shielded from the direct rays of the sun, so that the rods appeared steady and clear, and when sighting across the river it was possible to keep the instrument in the shade, and the even temperature near the water prevented, on these long sights, any movement of the rod from refraction. The worst country we passed over was the stretch from the seashore to the railroad bridge over the Deseado, near our bench No. 3. There was a stiff breeze blowing all the time, there were no trees in the swamp, and when it was not raining, the sun beat directly down on the line making the refraction very bad.

The work of the first or leading party was much more difficult, and as the organization and duties of the laborers differed in the two parties, their position could not be changed to advantage. The greater part of the way from Greytown to the Boca San Carlos, I kept instrument No. 1 ahead with my two most experienced men as instrument man and recorder. The second party followed closely, setting their turning points in the same places as the first party, as any change would mean clearing a new line. My instrument men were changed at the Boca San Carlos, and before we reached Bench No. 13, one of the new men received an appointment in the army.

At bench No. 13, I took instrument No. 1 and did my own recording, part of the time running ahead, but most of the time keeping behind instrument No. 3. I could start in a day's run behind the first party, and catch up with them by the end of the third day, and this gave me one day in four to go ahead on line and for other work. In very difficult places, such as the long sites on the river below San Carlos, both parties worked together first using one instrument and then the other.

If the levels at any time showed a difference greater than .03 feet into the square root of the

number of miles run by one level, the lines were re-run. The re-runnings were nearly all in the broken hilly country. In the river bottoms where the lines were practically level, the elevations given by the instruments, kept more nearly the same distance apart.

Instrument No. 1 was kept ahead from Greytown to the Boca San Carlos, and instrument No. 3, from the Boca San Carlos to Brito. With instrument No. 1 from Bench No. 1 to Bench No. 8 at the Chanchos river, G. F. Seymour was observer and J. A. Mitchell recorder. From Bench No. 8 to Bench No. 11 at the Boca San Carlos, G. F. Seymour was observer and A. E. L. Pain recorder. From Bench No. 11 to Bench No. 13 at La Cruz, John Carmichael was observer and A. E. L. Pain recorder. From Bench No. 13 to Bench No. 24 at Brito, Stephen Harris was observer and recorder.

With instrument No. 3, R. B. Post was observer, and E. S. Wilson recorder from Bench No. 1 to Bench No. 11, at the Boca San Carlos. From Bench No. 11 to Bench No. 14 at Machuca, L. E. Lannan was observer and E. S. Wilson recorder. From Bench No. 14 to Bench No. 24 at Brito, L. E. Lannan was observer and J. O. Jones recorder. J. O. Jones kept the office copy of the notes and had charge of the camp outfit from Greytown to Machuca.

I had A. E. L. Pain moving camp and cutting line from Bench No. 13 at La Cruz to Bench No. 20 at San Carlos, and F. R. Torrington cutting line and moving camp from Castillo to Brito. I kept with me two Spaniards as rodmen from Greytown to Brito, Leonidas Ochoa, a Colombian, and Ramon Hurtado of Rivas.

The party landed in Greytown, Saturday, December 18 and spent from that time till January 5 in testing instruments, collecting the camp outfit, and working on the Greytown tide gages. Work on the level line was commenced January 6, and was finished November 2, 1898.

The field records were in 27 ordinary level books, 13 for instrument No. 1, and 14 for instrument No. 3. These books gave the readings as recorded each day with the elevations; those east of the lake being derived from the Canal Company's bench at the machine shop at Greytown; those west of the lake being derived from the Canal Company's Pacific levels by using a bench near Las Lajas on the west shore of Lake Nicaragua made by J. W. G. Walker, assistant engineer.

No corrections to the elevations for lack of adjustment in the level, or for variations from the standard in the graduation of the rods, were made in the field.

There was also a cross section book used as a bench book giving a sketch showing the location of each bench, the elevations at each bench, and of prominent marks between it and the next bench, and the checks with other lines, and there were copied records of the field notes for both instruments as far as Bench No. 14 at Machuca. In addition to these records, there was given to us at Washington, the records of the tide-gage readings at Greytown, and at Brito, the Atlantic and Pacific terminals of the canal, and the gage readings at San Carlos and Lajas by which the levels on the two sides of the lake were to be connected.

The work then still to be done was to have the rods compared with the International Standard Meter, and correct the original readings accordingly, to apply a correction to the work corresponding to the observed want of adjustment and the difference between the backsights and foresights, and to refer all elevations to mean Atlantic sea level, and to see how much the Pacific mean sea level differed from the Atlantic.

The new elevations obtained in this way must then be recorded in such form as to be easily accessible and the bench marks so described as to be easily found. In this work, which was done in Washington, I was assisted by Louis E. Lannan and James O. Jones.

The rods were compared with the International Standard Meter by the Coast Survey Office of Standard Weights and Measures, and a table was sent us giving the correction for each decimeter of each of the four rods. The corrections were very slight, the maximum being seven-tenths of a millimeter for the eleventh decimeter of rod XVI. These corrections did not vary regularly from top to bottom of the rod, and to use them at all it was necessary to correct each reading. To do this, the original readings were copied on printed sheets made for this purpose, and then the corrected readings inserted and the elevations worked out over again. As the calculations in the field were made under very unfavorable circumstances, many of them at night under a wet mosquito bar, this recalculation gave the necessary check on the accuracy of the field computation.

The corrections for lack of adjustment were made as the elevations were recalculated, taking the lengths of the sights from the millimeters intercepted on the rods by the outside wires. As the sights were kept nearly equal, these corrections amounted to practically nothing. For instrument No. 3 the total accumulated correction at the end of the line was one millimeter, and for instrument No. 1, the corrections balanced out at bench No. 13, and west of that bench, while the adjustments were examined each morning, no corrections were noted for the instrument, as the adjustment varied slightly, with the focusing, due to a fall the instrument had at that place.

The elevations of all points likely to be wanted for future use were then converted from meters to United States feet by using the ratio one meter equals 39.37 inches.

These elevations with a description of the points where they were taken, will be given in the following pages. A sketch of a numbered bench will be given first and will be followed by the elevations and description of the points read near this bench, and between it and the succeeding numbered bench. For the purpose of showing there can be no large error in our work, there is afterward given a comparison of our levels with those of a third line formed by lines run by H. H. Trundle, assistant engineer, from Greytown to Ochoa; F. L. Stuart, assistant engineer, from Ochoa to San Carlos; the Canal Co. and J. W. G. Walker, assistant engineer, from San Carlos to Brito.

The Greytown tide-gage readings from which mean sea level is deduced, were taken between January 14, 1898 and September 14, 1898. The first gages were placed opposite the Canal Company's building at La Fé and about half a mile west of the Greytown light-house, and 150 feet northeast of our No. 1 bench.

They were protected from the waves by a sand-bar which was forming some 500 feet out to sea. An effort was made in placing gages at this point to get them as near as possible to the open sea, and so make sure they would not be affected by the discharge from the river. As the coast line is changing rapidly at this point, there are several breaks in the record, caused by storms carrying away the gages. The first gages were staff gages, and then a box gage was added. The readings were taken at this place till April 3, when the bar closed in front of the gage and cut it off from the sea. The gage was then moved to the mouth of the Rio Indio, 3½ miles

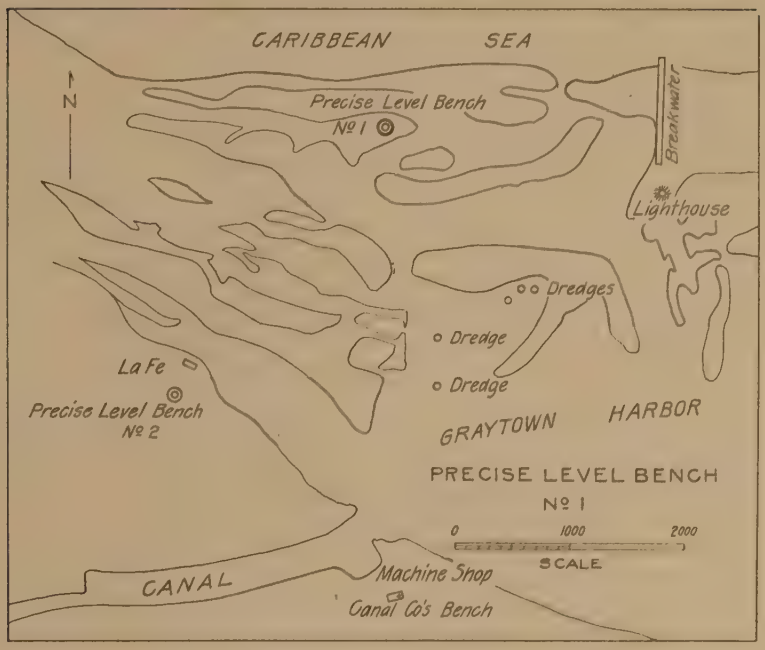
northwest of La Fé and readings were taken there from April 7, 1898, to June 30, 1898. At that time a new passage had formed from the Greytown lagoon to the sea past the Greytown light-house. The gage was changed to this place and readings taken from July 8 to September 14.

The gages at these three places were referred to the Canal Company's zero, by connecting them with our permanent bench No. 1 and using 2.520 ft. as the elevation of that bench. The gage was read every half hour. The half-hourly readings have been plotted as ordinates, and a curve drawn showing the rise and fall of the sea during the twenty-four hours. From this curve, mean sea level for the day was obtained by finding a horizontal line having equal areas above and below, between it and the curve, the difference between this line and the Canal Company's zero giving the mean height of the sea for that day. These daily mean sea level values were then plotted as ordinates, the line joining their extremities showing the variation of mean daily sea level. There are several marked changes in the height of this line, the most noticeable of which is that between July 17 and 21, during which time there was a change in mean sea level of nearly a foot. This change coincides with the heaviest rainfall during the period the readings were taken.

On July 19, 2.42 inches of rain fell, and on July 20, 5.18 inches. In order to see if there was any connection between the rainfall and the record of the gage, a curve was plotted showing the accumulated excess or deficiency of the rainfall as compared with the average from January 1 to October 31. The comparison of these curves shows either that the height of the sea near the gage was affected by the rain, or that both were due to the same cause, the northeast wind which brought the rain.

The mean of all the daily mean sea levels giving each day an equal value, showed mean sea level to be .524 ft. below the Canal Company's zero. Quite a number of days are missing in the record, as the gages were often disturbed by storms, and giving each month an equal value, changes this figure to .527 ft. below the Canal Company's zero. Again if 29-day periods are selected as is usual in this work, the figure is changed to .464 ft. below the Canal Company's zero, but by this method it is only possible to include 145 out of 212 readings taken, or 68 per cent. of the readings. Taking the different places, the readings at La Fé showed mean sea level to be .555 ft. below the Canal Company's zero; those at Rio Indio .668 ft. below; and those at Greytown light-house .337 ft. below. The value .524 ft., equivalent to .1597 meter, has been taken as probably nearest the true value, and none of the other values differs from this by as much as two-tenths of a foot. This makes the height of our permanent bench No. 1, 3.044 ft. above mean sea level, which is equivalent to .9278 meter.

The highest tide observed was January 21 and was 1.3 ft. above mean sea level. The lowest tide observed was May 25 and was 1.3 ft. below mean sea level, making the extreme range 2.6 ft. The mean of the daily highest water elevations was 0.47 ft. above mean sea level. The mean of the daily lowest water elevations was 0.32 ft. below mean sea level.



PRECISE LEVEL BENCH No. 1.

		Mean Elevation above Sea Level.
Temporary Bench No. 1	.7911 m.	2.595 ft.
Permanent Bench No. 1, on glass	.9278 m.	3.044 ft.
Permanent Bench No. 1, on cement	.9076 m.	2.978 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 1	.7910 m.	2.595 ft.	.7911 m.	2.595 ft.
Permanent Bench No. 1, on glass	.9278 m.	3.044 ft.	.9278 m.	3.044 ft.
Permanent Bench No. 1, on cement	.9062 m.	2.973 ft.	.9089 m.	2.982 ft.

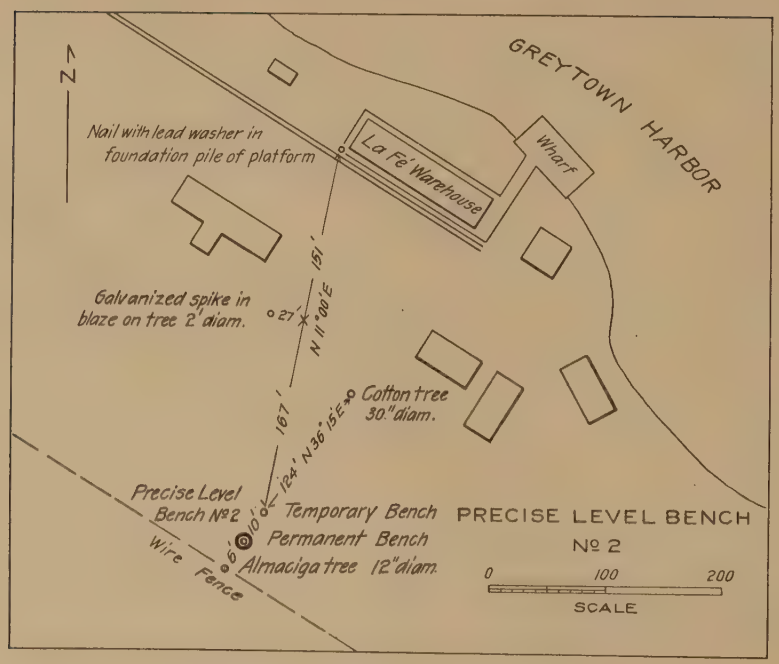
The first permanent bench was put in 150 feet southwest of the tide gage, opposite the Canal Company's buildings at La Fé, at the west end of Greytown harbor.

Its location is marked in the accompanying sketch by the heavy black circle surrounding a smaller circle.

Temporary bench No. 1 is 23 feet north of the permanent bench, and is a railroad spike driven in a wooden pile sunk level with the surrounding beach. It was placed January 6th, 1898.

Permanent bench No. 1 is a glass telegraph insulator set in a mass of cement mortar, 36 inches in diameter and 20 inches in depth. "B. M. No. 1 N. C. C. 1897-8" was marked on the mortar. The top of the insulator was level with the surrounding beach, and was covered with a mound of driftwood and sand. Permanent bench No. 1 was built January 10th, 1898. Readings were taken January 11th on the glass insulator, and also on the cement mortar at the side of the insulator.

In running from bench No. 1 to bench No. 2 the backsights were read first by both instruments.



PRECISE LEVEL BENCH No. 2.

	Mean Elevation above Sea Level.	
Temporary Bench No. 2, on glass	1.7548 m.	5.757 ft.
Temporary Bench No. 2, on cement	1.7439 m.	5.721 ft.
Permanent Bench No. 2, on glass	1.6267 m.	5.337 ft.
Permanent Bench No. 2, on cement	1.6029 m.	5.259 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 2, on glass	1.7519 m.	5.748 ft.	1.7576 m.	5.766 ft.
Temporary Bench No. 2, on cement	1.7412 m.	5.713 ft.	1.7466 m.	5.730 ft.
Permanent Bench No. 2, on glass	1.6241 m.	5.328 ft.	1.6293 m.	5.345 ft.
Permanent Bench No. 2, on cement	1.5998 m.	5.249 ft.	1.6060 m.	5.269 ft.

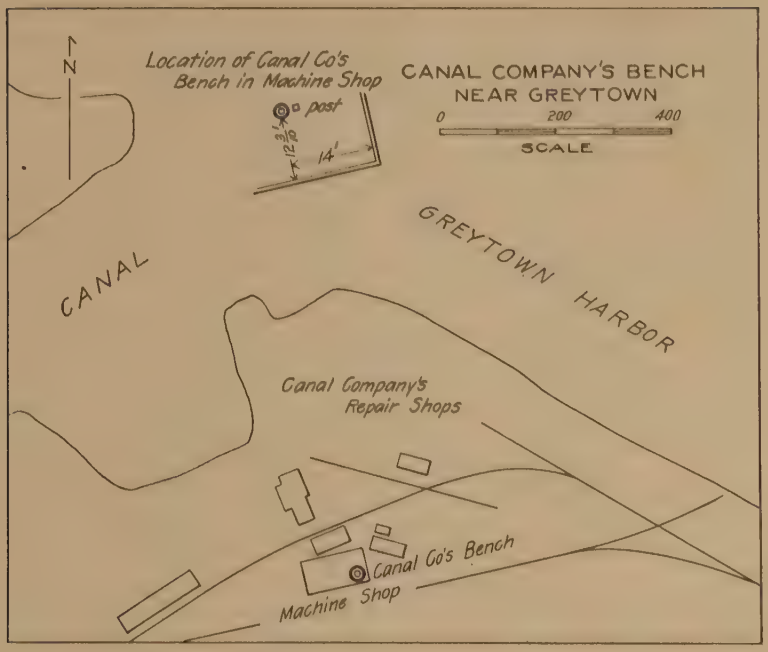
Bench No. 2 is 0.9 of a mile by the line of levels from bench No. 1, and is the main bench for our line of levels. Its location near the Canal Company's buildings at La Fé is shown in the accompanying sketch.

Temporary bench No. 2 is a glass telegraph insulator set in a prism of concrete mortar 12 inches square and 24 inches deep. The top of the insulator is level with the top of the surrounding surface. Readings were taken on the glass insulator and on the cement mortar at the side of the insulator.

Permanent bench No. 2 is a glass telegraph insulator, set in a mass of cement mortar 48 inches in diameter and 20 inches deep. The top of the insulator is 36 inches below the surface. The bench is covered by a mound of earth. "B. M. No. 2, N. C. C. 1897-8" was marked on the mortar.

This bench was built January 11th, 1898. Readings were taken on the glass insulator and on the cement mortar at the side of the insulator, January 12th for instrument No. 1, and January 15th for instrument No. 3.

With instrument No. 1 we ran from the Canal Company's bench in the machine shop to bench No. 2, reading backsights first. With instrument No. 3 we ran from bench No. 2 to the Canal Company's bench in the machine shop, reading backsights first.



CANAL CO.'S BENCH IN MACHINE SHOP.

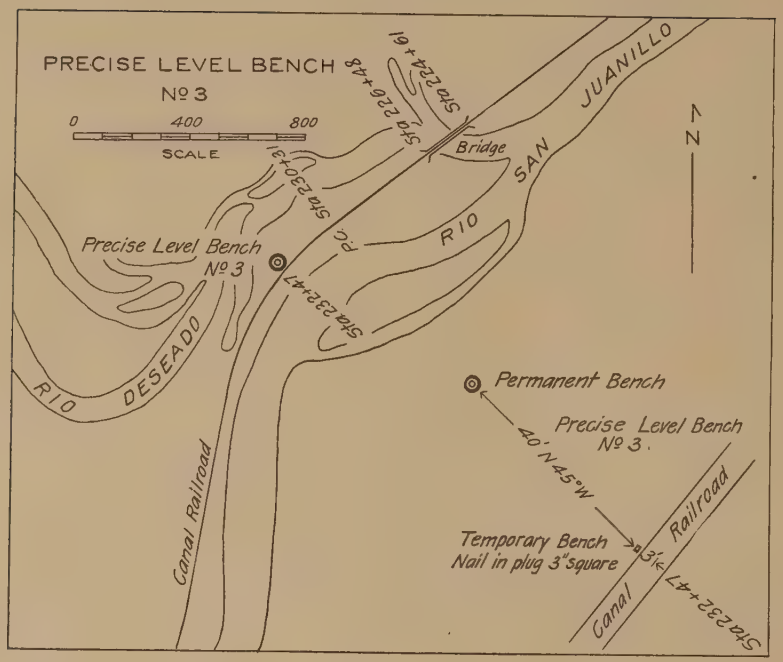
	Mean Elevation above Sea Level.	
Canal Co.'s Bench in Machine Shop	1.5417 m.	5.058 ft.

	Instrument No. 1.		Instrument No. 3.	
Canal Company's Bench in Machine Shop	1.5374 m.	5.044 ft.	1.5459 m.	5.072 ft.

The Canal Company's main bench is in their machine shop, about a mile west of Greytown, where their canal enters Greytown harbor, and is 0.7 of a mile from our bench No. 2. "B. M. + 4.538" is cut in a movable board of the machine shop floor, under which is a copper point set in masonry, to which is attached a sheet copper tag marked "+ 4.538." This elevation gives the height of the bench above mean water level in the Greytown lagoon as determined by the Canal Company, and was used by us in finding the field elevations of the benches east of Lake Nicaragua.

The gagings made by this Commission near Greytown, and our corrected level line, show mean sea level to be .520 foot below the Canal Company's datum, and the elevation of this bench to be as given in the above table.

In running to bench No. 3 the backsights were read first.



PRECISE LEVEL BENCH No. 3.

	Mean Elevation above Sea Level.	
Temporary Bench No. 3	4.6839 m.	15.367 ft.
Permanent Bench No. 3, on glass	6.8576 m.	22.499 ft.
Permanent Bench No. 3, on cement	6.8352 m.	22.425 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 3	4.6985 m.	15.415 ft.	4.6692 m.	15.319 ft.
Permanent Bench No. 3, on glass	6.8715 m.	22.544 ft.	6.8436 m.	22.453 ft.
Permanent Bench No. 3, on cement	6.8491 m.	22.471 ft.	6.8212 m.	22.379 ft.

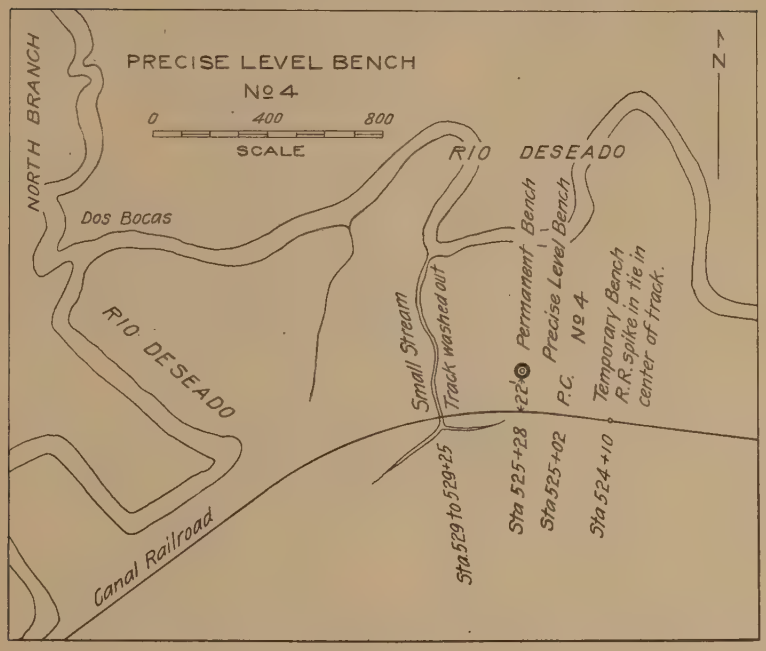
Bench No. 3 is 4.4 miles from the Canal Company's bench near Greytown. It is at the side of the canal railroad, near the junction of the San Juanillo and the Deseado rivers.

Temporary bench No. 3 is a nail driven in a three-inch square plug at the right side of the track at station 232 + 47.

Permanent bench No. 3 is 40 feet northwest of the temporary bench, and is a glass telegraph insulator set in a mass of cement mortar marked "B. M. No. 3, N. C. C. 1897-8." The top of the insulator is 30 inches below the surface. This bench was made January 15th and the elevation taken on the glass insulator and on the cement mortar at the side of the insulator, by instrument No. 1, January 17th, and by instrument No. 3, January 18th.

The difference between the two level lines at a point just west of the Canal Company's bench exceeds the limit allowed of 0.03 foot into the square root of the number of miles run by one level, and this part of the line would have been re-run had there not been an error in the calculated field elevations in the notes for instrument No. 3, which was not corrected till the work was gone over in Washington, and which made the elevations appear to be keeping together.

From bench No. 3 to bench No. 4 the backsights were read first.



PRECISE LEVEL BENCH No. 4.

	Mean Elevation above Sea Level.	
Temporary Bench No. 4	7.1488 m.	23.454 ft.
Permanent Bench No. 4, on glass	7.5865 m.	24.890 ft.
Permanent Bench No. 4, on cement	7.5705 m.	24.838 ft.

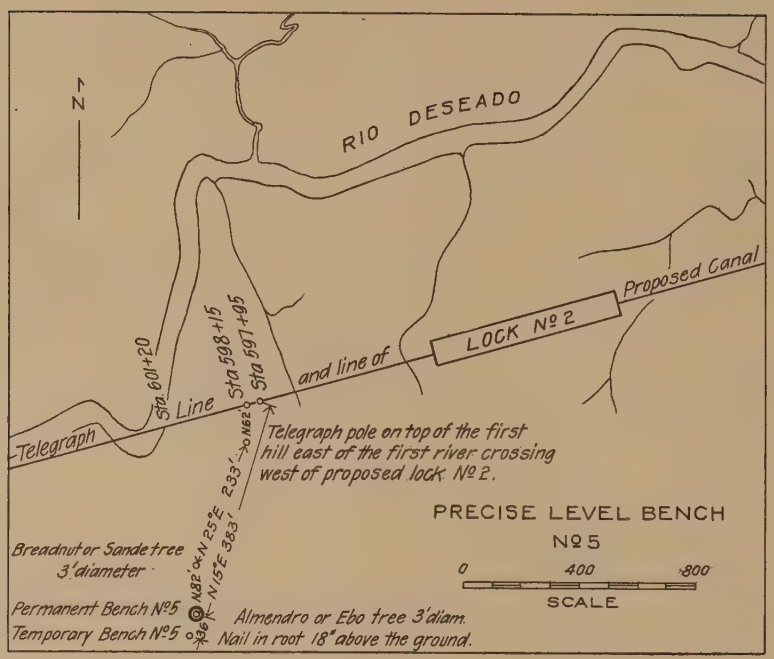
	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 4	7.1540 m.	23.471 ft.	7.1435 m.	23.437 ft.
Permanent Bench No. 4, on glass	7.5936 m.	24.913 ft.	7.5793 m.	24.866 ft.
Permanent Bench No. 4, on cement	7.5779 m.	24.862 ft.	7.5630 m.	24.813 ft.

Bench No. 4 is 5.5 miles beyond bench No. 3, and half a mile east of the Canal Company's location for their No. 1 lock.

Temporary bench No. 4 is a railroad spike in the center of the track in a tie at station 524 + 10.

Permanent bench No. 4 is a glass telegraph insulator set in a mass of cement mortar 30 inches below the surface. It is 22 feet to the right of station 525 + 28. "B. M. No. 4 N. C. C. 1897-8" is marked in the cement. The bench was built January 21st, 1898, and elevations taken on the glass insulator and on the mortar at the side of the insulator, by instrument No. 1, January 24th, and by instrument No. 3, January 26th.

From bench No. 4 to bench No. 5 the backsights were read first.



PRECISE LEVEL BENCH No. 5.

	Mean Elevation above Sea Level.	
Temporary Bench No. 5	27.9598 m.	91.731 ft.
Permanent Bench No. 5, on glass	28.7602 m.	94.357 ft.
Permanent Bench No. 5, on cement	28.7276 m.	94.250 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 5	27.9612 m.	91.736 ft.	27.9584 m.	91.727 ft.
Permanent Bench No. 5, on glass	28.7628 m.	94.366 ft.	28.7576 m.	94.349 ft.
Permanent Bench No. 5, on cement	28.7298 m.	94.258 ft.	28.7254 m.	94.243 ft.

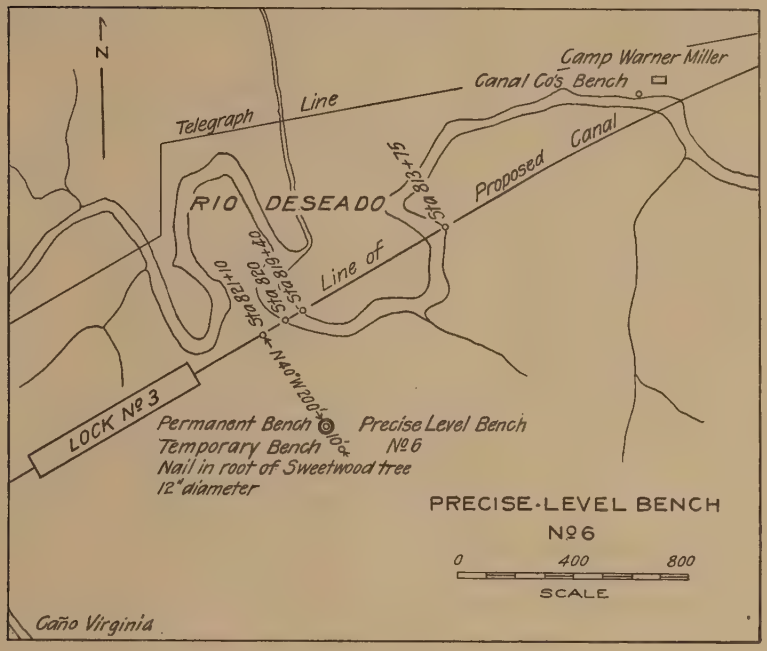
Bench No. 5 is 2.3 miles by our line of levels beyond bench No. 4, and is just west of the Canal Company's location for their No. 2 lock.

Temporary bench No. 5 is a nail in the root of an almendro or ebo tree, 3 feet in diameter. The bench is 18 inches above the ground.

Permanent bench No. 5 is a glass telegraph insulator set in a mass of cement mortar 30 inches below the surface. "B. M. No. 5 N. C. C. 1897-8" is marked on the mortar.

This bench was made February 1st and elevations were taken on the glass insulator and on the cement mortar by the side of the insulator, by instrument No. 1, February 9th and by instrument No. 3 February 7th.

From bench No. 5 to bench No. 6 backsights were read first by both instruments.



PRECISE LEVEL BENCH No. 6.

	Mean Elevation above Sea Level.	
Temporary Bench No. 6	38.4384 m.	126.110 ft.
Permanent Bench No. 6, on glass	37.4092 m.	122.733 ft.
Permanent Bench No. 6, on cement	37.3814 m.	122.642 ft.
Canal Co.'s Bench	18.0288 m.	59.149 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 6	38.4332 m.	126.093 ft.	38.4436 m.	126.127 ft.
Permanent Bench No. 6, on glass	37.4040 m.	122.716 ft.	37.4143 m.	122.750 ft.
Permanent Bench No. 6, on cement	37.3764 m.	122.626 ft.	37.3863 m.	122.658 ft.
Canal Company's Bench	18.0262 m.	59.141 ft.	18.0313 m.	59.158 ft.

Bench No. 6 is 5.2 miles by the level line and 4.2 miles measuring along the Canal Company's center line of the canal from bench No. 5. It is just east of the Canal Company's location for their No. 3 lock.

Temporary bench No. 6 is a nail in the root of a sweetwood tree 12 inches in diameter.

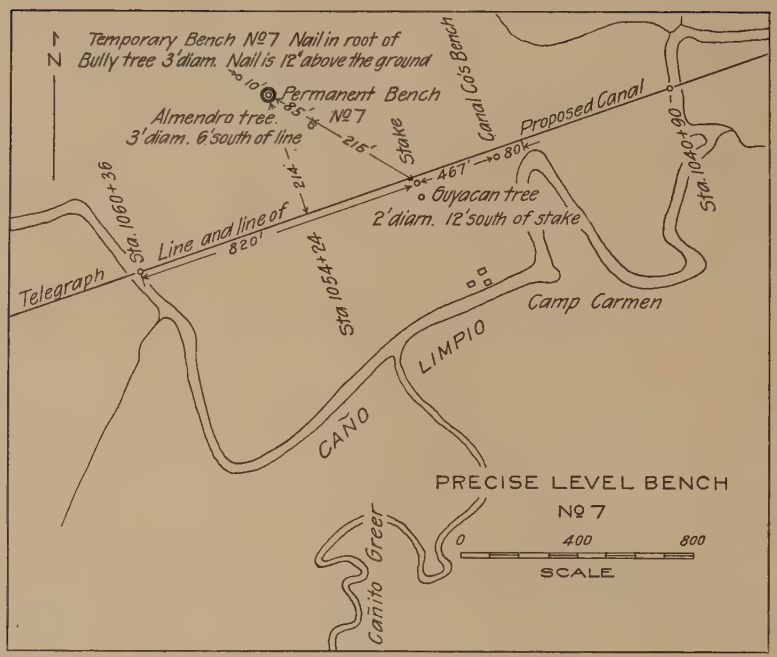
Permanent bench No. 6 is a glass telegraph insulator set in a mass of cement mortar. The insulator is 24 inches below the surface and is covered by a mound of earth. "B. M. No. 6 N. C. C. 1897-8" is marked in the cement mortar.

This bench was made March 12th, 1898, and elevations were taken on the glass insulator and on the cement mortar by the side of the insulator, March 14th.

About 1500 feet northeast of our bench is an old Canal Company's bench, recorded in their notes as "No. 34 Molinas check levels, Camp Warner Miller, 20 feet left Sta. 845, Elevation 58.42 feet." This bench is a copper bolt in the root of a tree near the water's edge, just above Camp Warner Miller.

From bench No. 6 to bench No. 7 backsights were read first by instrument No. 1 and foresights first by instrument No. 3.

Our line west of bench No. 6 passed over the divide 1500 feet north of the Canal Company's center line for the canal, following their railroad line, and the maximum elevation was 298.75 feet.



PRECISE LEVEL BENCH No. 7.

	Mean Elevation above Sea Level.	
Temporary Bench No. 7	42.2976 m.	138.771 ft.
Permanent Bench No. 7, on glass	41.1104 m.	134.876 ft.
Permanent Bench No. 7, on cement	41.0707 m.	134.746 ft.
Canal Co.'s Bench	30.3745 m.	99.654 ft.
Spike at Chanchos River Crossing	16.0079 m.	52.519 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 7	42.3069 m.	138.802 ft.	42.2882 m.	138.741 ft.
Permanent Bench No. 7, on glass	41.1188 m.	134.904 ft.	41.1019 m.	134.848 ft.
Permanent Bench No. 7, on cement	41.0805 m.	134.778 ft.	41.0609 m.	134.714 ft.
Canal Company's Bench	30.3844 m.	99.686 ft.	30.3645 m.	99.621 ft.
Spike at Chanchos River Crossing	16.0088 m.	52.522 ft.	16.0070 m.	52.516 ft.

Bench No. 7 is 7.5 miles by our level line and 4.4 miles by the Canal Company's center line of the canal from bench No. 6.

Temporary bench No. 7 is a nail in the root of a bully tree 3 feet in diameter. The nail is 12 inches above the ground.

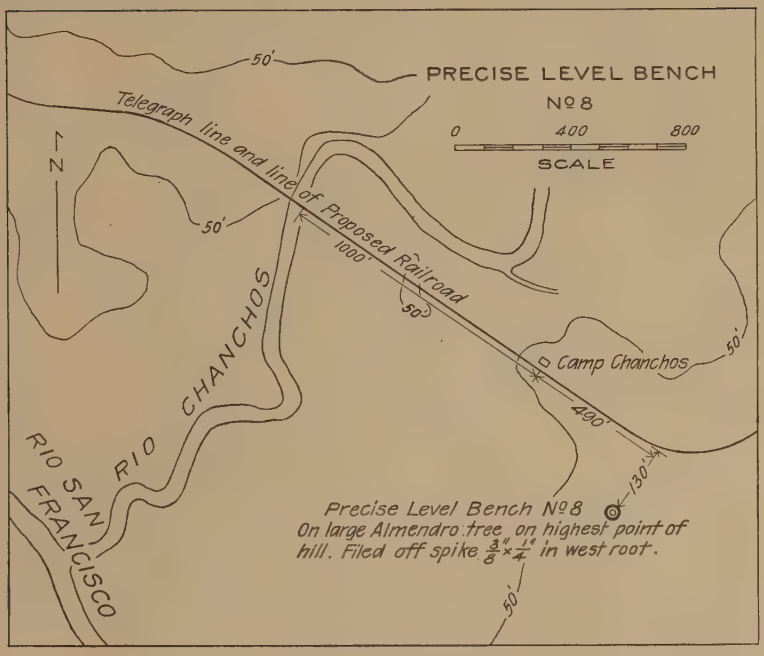
Permanent bench No. 7 is a glass telegraph insulator set in a mass of cement mortar. The insulator is 24 inches below the surface. "B. M. No. 7 N. C. C. 1897-8" is marked on the cement. This bench was made March 23d and elevations were taken on the insulator, and on the cement mortar by the side of the insulator, by instrument No. 1, March 24th, and by instrument No. 3, March 25th.

700 feet east of our No. 7 bench is an old Canal Company's bench, recorded in their notes as "On redwood tree 14 inches in diameter at Sta. 139 + 68, Perez Canal Location, Divide, marked XX, copper bolt, El. 99.727 ft.

$$\frac{1.}{98.727\ \text{ft.}}$$

." The tree has been cut down, but the copper bolt is in the stump of tree in the telegraph clearing.

From bench No. 7 to bench No. 8 backsights were read first by both instruments. Where the canal line leaves the Chanchos, we have made a bench by driving a spike in the root of a 60-inch tree at Trundle's station 1117 + 80 on the east bank of the river.



PRECISE LEVEL BENCH No. 8.

	Mean Elevation above Sea Level.	
Bench No. 8	45.7774 m.	150.188 ft.
River gage bench near Camp Chanchos	15.8135 m.	51.881 ft.
River gage bench near Camp Frisco	15.7180 m.	51.568 ft.

	Instrument No. 1.		Instrument No. 3.	
Bench No. 8	45.7767 m.	150.186 ft.	45.7780 m.	150.190 ft.
River gage bench near Camp Chanchos	15.8144 m.	51.884 ft.	15.8125 m.	51.878 ft.
River gage bench near Camp Frisco	15.7195 m.	51.573 ft.	15.7165 m.	51.563 ft.

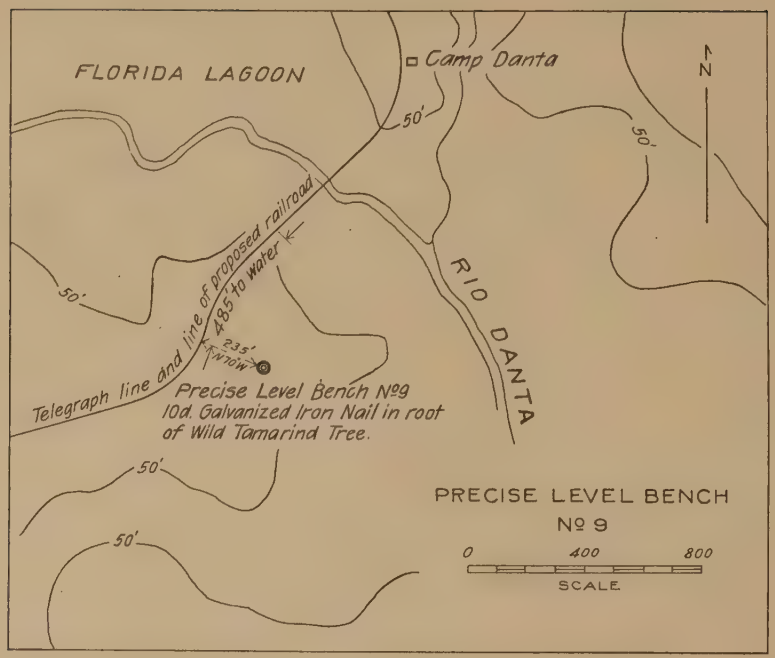
Bench No. 8 is three miles by our level line, and two miles by the Canal Company's center line of the canal, beyond bench No. 7. It is a filed-off spike ⅜ x ¼ inch in the west root of a large almendro tree on the top of a hill just west of where the telegraph line last crosses the Chanchos. It was driven April 2nd, 1898, and readings were taken by instrument No. 1, April 12th, and by instrument No. 3, April 2nd.

A river gage was placed by the hydrographic party on the Chanchos river about half a mile above the telegraph crossing and near Camp Chanchos, and a bench was made by them and connected with the gage rod. Our readings on this bench are given above.

On the San Francisco river, just below the telegraph crossing, and near Camp Frisco, there is a gage and bench placed by the hydrographic party, near Trundle's station 1250. Our readings on this bench are given above.

Our line between benches No. 8 and No. 9 followed the San Francisco river to the San Francisco telegraph crossing and then followed the Caño Surprise to the Danta river, and the Danta to the Danta telegraph crossing.

From bench No. 8 to bench No. 9, backsights were read first by instrument No. 1 and foresights first by instrument No. 3.



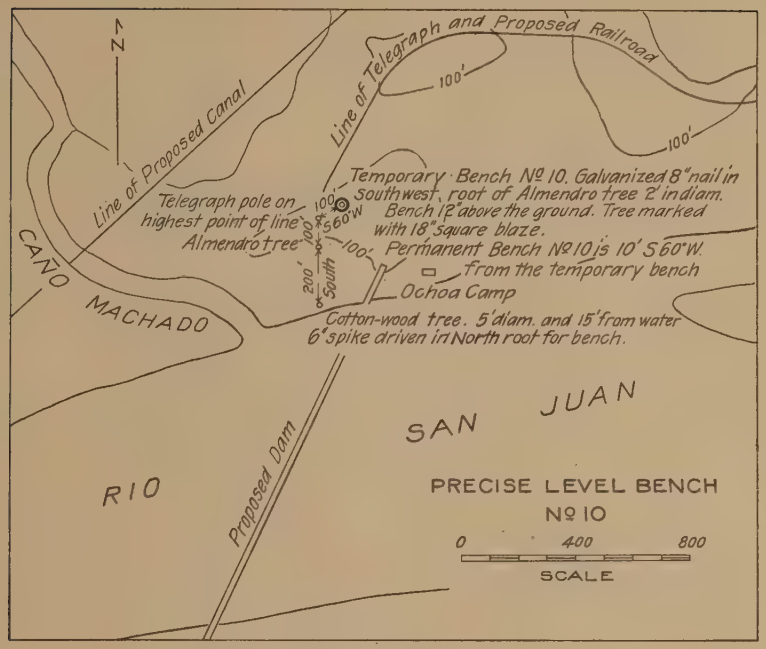
PRECISE LEVEL BENCH No. 9.

	Mean Elevation above Sea Level.	
Bench No. 9	36.7239 m.	120.485 ft.

	Instrument No. 1.		Instrument No. 3.	
Bench No. 9	36.7274 m.	120.497 ft.	36.7204 m.	120.474 ft.

Bench No. 9 is 7 miles by our level line, and 5 miles by the Canal Company's center line of the canal beyond bench No. 8. It is on top of a hill on the south side of the Danta river, and is 235 feet east of the telegraph line. This bench is a 10d. galvanized iron nail in the root of a wild tamarind tree, driven April 28th, 1898. Readings were taken April 29th.

The line between benches No. 9 and No. 10 follows the telegraph line. Backsights were read first by both instruments.


N
Line of Telegraph and Proposed Railroad
100'
100'
Line of Proposed Canal
Temporary Bench No 10. Galvanized 8" nail in southwest root of Almendro tree 2' in diam. Bench 12" above the ground. Tree marked with 18" square blaze.
Telegraph pole on highest point of line
Almendro tree
100'
S 60° W
100'
Permanent Bench No 10 is 10' S 60° W. from the temporary bench
200' South
Ochoa Camp
CAÑO MACHADO
Cotton-wood tree. 5' diam. and 15' from water
6" spike driven in North root for bench.
SAN JUAN
RIO
Proposed Dam
PRECISE LEVEL BENCH
No 10
0 400 800
SCALE

PRECISE LEVEL BENCH No. 10.

	Mean Elevation above Sea Level.	
Temporary Bench No. 10	39.4737 m.	129.507 ft.
Permanent Bench No. 10, on spike	38.6851 m.	126.919 ft.
Permanent Bench No. 10, on stone	38.6766 m.	126.892 ft.
Spike in Cottonwood at Ochoa	20.8305 m.	68.341 ft.
Bench opposite Ochoa Hydrographic Camp	21.8674 m.	71.743 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 10	39.4761 m.	129.515 ft.	39.4712 m.	129.498 ft.
Permanent Bench No. 10, on spike	38.6873 m.	126.927 ft.	38.6829 m.	126.912 ft.
Permanent Bench No. 10, on stone	38.6792 m.	126.900 ft.	38.6740 m.	126.883 ft.
Spike in Cottonwood at Ochoa	20.8308 m.	68.342 ft.	20.8302 m.	68.341 ft.
Bench opposite Ochoa Hydrographic Camp	21.8685 m.	71.747 ft.	21.8663 m.	71.740 ft.

Bench No. 10 is 5.7 miles by our level line, and 4.5 miles by the Canal Company's center line of the canal, beyond bench No. 9.

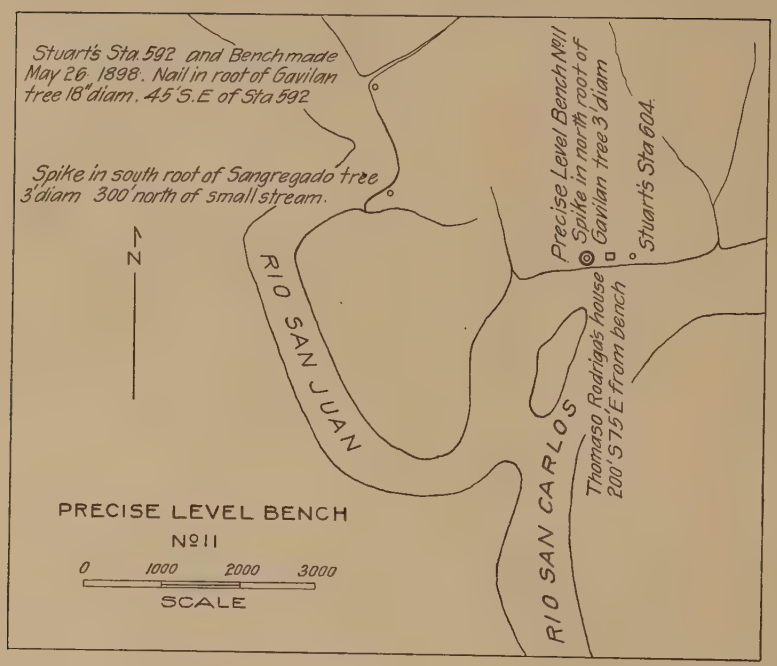
Temporary bench No. 10 is a galvanized 8-inch spike in the southwest root of an almendro tree, 2 feet in diameter. The bench is 18 inches above the ground. The tree is marked with an 18-inch square blaze.

Permanent bench No. 10 is a spike set with sulphur in a stone buried 3 feet below the surface, 10 feet southwest of the temporary bench. "B. M. No. 10 N. C. C. 1898" is cut in the stone. This bench was made May 18th, and elevations were taken on the spike and on the stone at the side of the spike, May 26th.

We expected to find an old bench in the large cottonwood tree at Ochoa near the telegraph station, and have driven a 6-inch spike in the north root of this tree, the elevation of which is given above.

We made a bench by driving a nail in the root of a leaning almendro tree on the north bank of the San Juan river opposite the Ochoa hydrographic camp and 15 feet left of Trundle's station 1678 + 20.

The line between benches No. 10 and No. 11 follows the north bank of the river. Backsights were read first by instrument No. 1 and foresights first by instrument No. 3.


Stuart's Sta. 592 and Bench made May 26. 1898. Nail in root of Gavilan tree 18" diam. 45' S.E of Sta 592
Spike in south root of Sangregado tree 3' diam 300' north of small stream.
N
RIO SAN JUAN
Precise Level Bench No 11 Spike in north root of Gavilan tree 3' diam
Stuart's Sta 604.
Thomaso Rodriga's house 200' S 75° E from bench
RIO SAN CARLOS
PRECISE LEVEL BENCH
No 11
0 1000 2000 3000
SCALE

PRECISE LEVEL BENCH No. 11.

	Mean Elevation above Sea Level.	
Bench No. 11	22.7615 m.	74.677 ft.
Spike in root of Sangregado tree	21.4222 m.	70.283 ft.
Bench near Stuart's Sta. 592	20.6303 m.	67.685 ft.

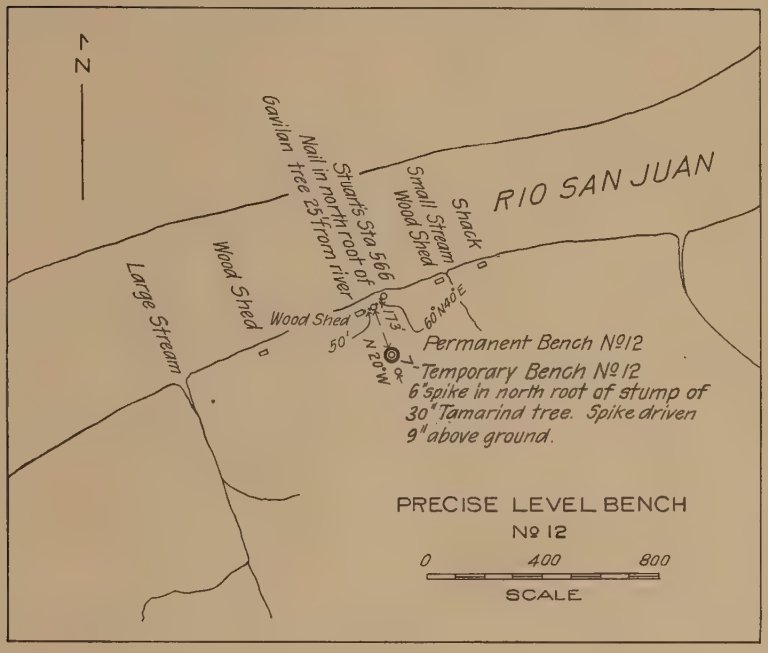
	Instrument No. 1.		Instrument No. 3.	
Bench No. 11	22.7584 m.	74.667 ft.	22.7646 m.	74.687 ft.
Spike in root of Sangregado tree	21.4149 m.	70.259 ft.	21.4294 m.	70.306 ft.
Bench near Stuart's Station 592	20.6238 m.	67.663 ft.	20.6368 m.	67.706 ft.

Bench No. 11 is 3.7 miles by our level line beyond bench No. 10, and is on the north bank of the San Juan near the telegraph station, and is opposite the mouth of the San Carlos river. This bench is a spike in the north root of a gavilan tree, 3 feet in diameter, and is 200′ N. 75° W. from Thomas Rodriga's house, in which is the telegraph station. This bench was made May 17th and readings taken May 17th by instrument No. 1 and May 23rd by instrument No. 3.

From this bench our line runs in a northwesterly direction till we meet the river again. Our maximum elevation on this cut-off was 178.7 feet.

When we reached the river again we made a bench by driving a spike in the south root of a sangregado tree, and 1500 feet farther ahead we made a bench near Stuart's station 592, by driving a nail in the root of a gavilan tree. From this point to bench No. 12 the line follows the north bank of the San Juan river.

Backsights were read first by both instruments between benches No. 11 and No. 12.



PRECISE LEVEL BENCH No. 12.

	Mean Elevation above Sea Level.	
Temporary Bench No. 12	38.3969 m.	125.974 ft.
Permanent Bench No. 12	36.8054 m.	120.752 ft.
Nail in Gavilan tree	20.4302 m.	67.028 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 12	38.3968 m.	125.974 ft.	38.3969 m.	125.974 ft.
Permanent Bench No. 12	36.8049 m.	120.751 ft.	36.8058 m.	120.754 ft.
Spike in Gavilan tree	20.4323 m.	67.035 ft.	20.4280 m.	67.021 ft.

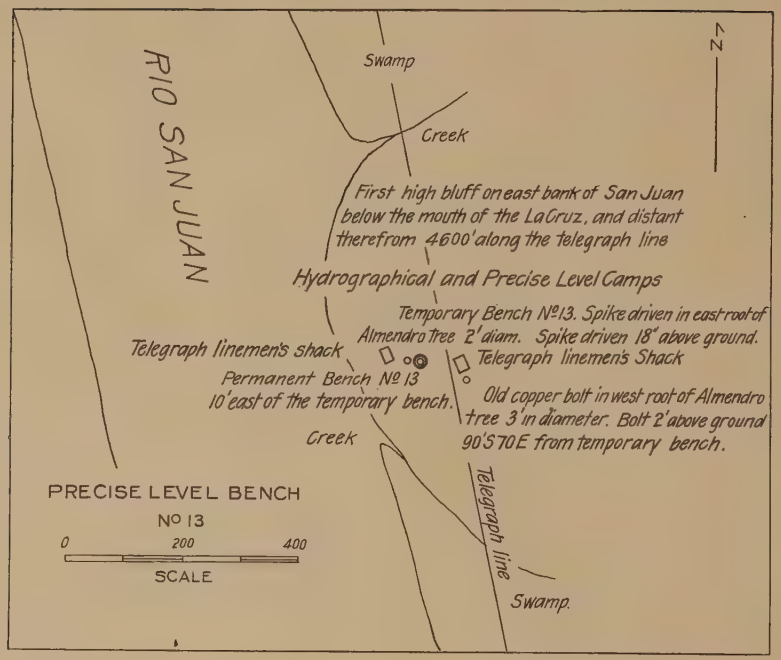
Bench No. 12 is 7 miles by our line beyond bench No. 11. It is in a large clearing near Stuart's station 566.

Temporary bench No. 12 is a 6-inch spike in the north root of a 30-inch tamarind tree. This bench is 9-inches above the ground.

Permanent bench No. 12 is the highest point of a round knob cut on a stone, set 2 feet below the surface, 7 feet north of the temporary bench. This bench was made June 20th and elevations were taken on it by instrument No. 1 June 20th, and by instrument No. 3 June 28th.

173 feet northwest of the permanent bench is a bench made by driving a nail in the north root of a gavilan tree, 25 feet from the river.

From bench No. 12 to bench No. 13 we followed the east bank of the San Juan river, and the foresights were read first by both instruments.


RIO SAN JUAN
Swamp
Creek
N
First high bluff on east bank of San Juan below the mouth of the La Cruz, and distant therefrom 4600' along the telegraph line
Hydrographical and Precise Level Camps
Temporary Bench No13. Spike driven in east root of Almendro tree 2' diam. Spike driven 18" above ground.
Telegraph linemen's shack
Telegraph linemen's Shack
Permanent Bench No 13 10' east of the temporary bench.
Old copper bolt in west root of Almendro tree 3' in diameter. Bolt 2' above ground 90' S 70 E from temporary bench.
Creek
PRECISE LEVEL BENCH
No 13
0 200 400
SCALE
Telegraph line
Swamp.

PRECISE LEVEL BENCH No. 13.

	Mean Elevation above Sea Level.	
Temporary Bench No. 13	28.1253 m.	92.274 ft.
Permanent Bench No. 13, on spike	27.1201 m.	88.977 ft.
Permanent Bench No. 13, on stone at side of spike	27.1142 m.	88.957 ft.
Old copper bolt	28.1126 m.	92.233 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 13	28.1292 m.	92.287 ft.	28.1214 m.	92.262 ft.
Permanent Bench No. 13, on stone at side of spike	27.1230 m.	88.986 ft.	27.1171 m.	88.967 ft.
Permanent Bench No. 13, on stone at side of spike	27.1170 m.	88.966 ft.	27.1114 m.	88.948 ft.
Old copper bolt	28.1169 m.	92.247 ft.	28.1082 m.	92.218 ft.

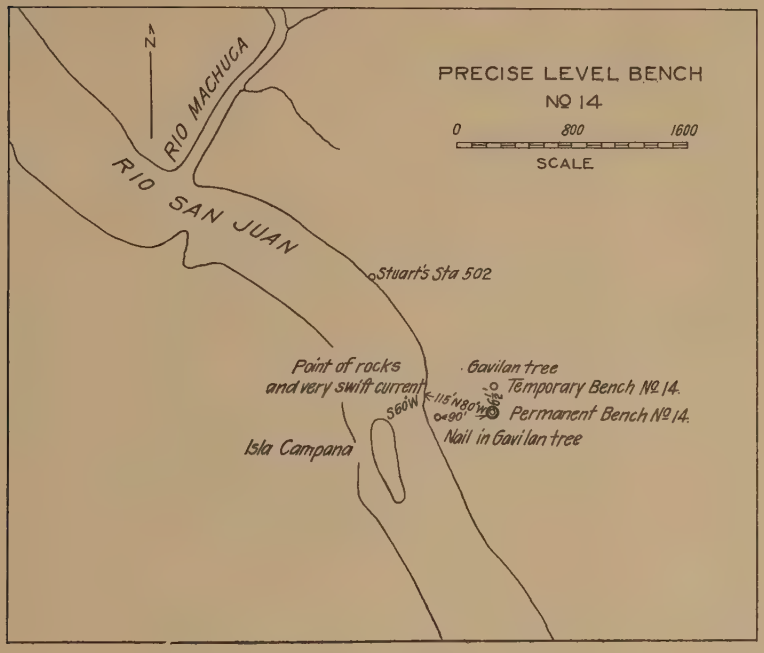
Bench No. 13 is 3.3 miles by our line beyond bench No. 12, and is on the first high bluff on the east bank of the San Juan river below the mouth of the La Cruz, and is where the telegraph line again meets the river after leaving it at Ochoa.

Temporary bench No. 13 is a spike in the east root of an almendro tree in the center of the clearing for the telegraph shacks. The tree is 2 feet in diameter and the bench is 18 inches above the ground.

Permanent bench No. 13 is 10 feet east of the temporary bench, and is a spike leaded in a stone buried 2 feet below the surface. This bench was made June 2nd and readings were taken on the spike, and on the stone at the side of the spike, by instrument No. 1 June 29th, by instrument No. 3 June 28th.

Readings were also taken on an old copper bolt in the west root of an almendro tree, 3 feet in diameter. This bench is 2 feet above the ground and is 90° S. 70° E. from the temporary bench. It was made by the Canal Company, but the elevation for it was not worked out by them.

From bench No. 13 to bench No. 14 our line followed the north bank of the river, and backsights were read first by both instruments.



PRECISE LEVEL BENCH No. 14.

	Mean Elevation above Sea Level.	
Temporary Bench No. 14	41.7639 m.	137.020 ft.
Permanent Bench No. 14	40.8164 m.	133.912 ft.
Nail in Gavilan tree	25.3173 m.	83.062 ft.
Nail in Jobo tree above Machuca river	23.5970 m.	77.418 ft.
Nail in stump, Agua Fresca river	24.5995 m.	80.707 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 14	41.7624 m.	137.015 ft.	41.7653 m.	137.025 ft.
Permanent Bench No. 14	40.8147 m.	133.906 ft.	40.8181 m.	133.917 ft.
Nail in Gavilan tree	25.3170 m.	83.061 ft.	25.3176 m.	83.063 ft.
Nail in Jobo tree above Machuca river	23.5932 m.	77.405 ft.	23.6008 m.	77.430 ft.
Nail in stump, Agua Fresca river	24.5969 m.	80.698 ft.	24.6021 m.	80.715 ft.

Bench No. 14 is seven miles by our line of levels beyond bench No. 13, and is half a mile below the mouth of the Machuca river. It is at a point of rock which juts out into the river just above Isla Campaña.

Temporary bench No. 14 is an 8-inch spike driven in the east root of a gavilan tree, 12 inches above the ground.

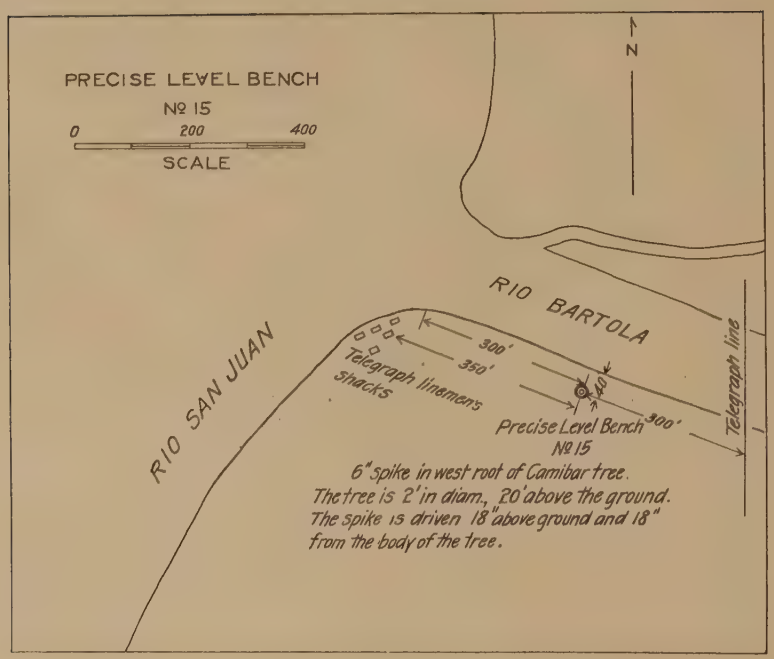
Permanent bench No. 14 is 6½ feet south of the temporary bench, and is 10 feet west of a sangregado tree, 2 feet in diameter, marked by a blaze 1 foot by 3 feet, and is 115 feet from the river, measuring along Stuart's cutting. This bench is a buried stone, on the highest point of which elevations were taken. The bench was made July 16th, and elevations taken by instrument No. 1 July 18th, and by instrument No. 3 July 16th.

We also made a bench 90 feet west of the permanent bench by driving a nail in a gavilan tree.

We made a bench 1100 feet above the Machuca river and 70 feet from the San Juan river, by driving a nail in the south root of a jobo tree 18 inches in diameter.

Where our line crosses the Agua Fresca river we drove a nail in a four-inch stump on the east bank of the river for a bench.

From bench No. 14 to bench No. 15 our line followed the north bank of the river and foresights were read first by both instruments.



PRECISE LEVEL BENCH No. 15.

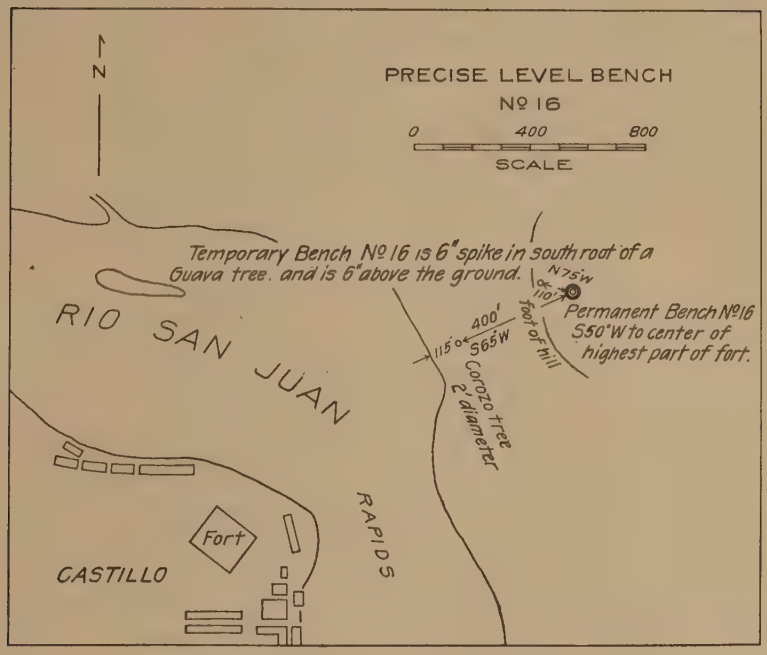
	Mean Elevation above Sea Level.	
Bench No. 15	27.3129 m.	89.609 ft.

	Instrument No. 1.		Instrument No. 3.	
Bench No. 15	27.3127 m.	89.608 ft.	27.3131 m.	89.610 ft.

Bench No. 15 is 8.5 miles by our line beyond bench No. 14, and is at the mouth of the Bartola river.

Bench No. 15 is a 6-inch spike in the west root of a camibar tree. The tree is 2 feet in diameter, 20 feet above the ground. The spike is driven 18 inches above the ground and 18 inches from the body of the tree. The tree is marked by a blaze 2 feet square. The bench was made and the readings were taken August 2nd.

From bench No. 15 to bench No. 16 our line follows the north bank of the river, and the backsights were read first by both instruments.



PRECISE LEVEL BENCH No. 16.

	Mean Elevation above Sea Level.	
Temporary Bench No. 16	31.4841 m.	103.294 ft.
Permanent Bench No. 16, on spike	39.4701 m.	129.495 ft.
Permanent Bench No. 16, on stone	39.4611 m.	129.465 ft.
Bench near Stuart's Sta. 210	29.8021 m.	97.776 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 16	31.4789 m.	103.277 ft.	31.4892 m.	103.311 ft.
Permanent Bench No. 16, on spike	39.4639 m.	129.474 ft.	39.4762 m.	129.515 ft.
Permanent Bench No. 16, on stone	39.4549 m.	129.445 ft.	39.4672 m.	129.485 ft.
Bench near Stuart's Station 210	29.7964 m.	97.757 ft.	29.8077 m.	97.794 ft.

Bench No. 16 is 5.7 miles by our line beyond bench No. 15, and is opposite Castillo.

Temporary bench No. 16 is a 6-inch spike in the south root of a guava tree, and is 6 inches above the ground.

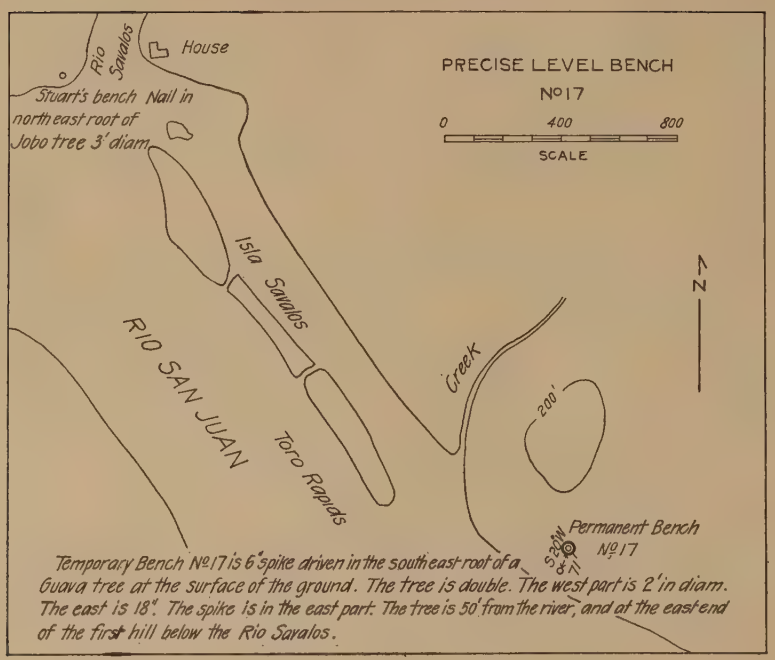
Permanent bench No. 16 is a spike set with sulphur in a stone buried 2 feet below the surface, and is 110 feet S. 75° E. from the temporary bench. This bench was made August 3rd, and elevations were taken on the spike, and on the stone at the side of the spike, by instrument No. 1 August 12th and by instrument No. 3 August 9th.

300 feet west of Stuart's station 210 we made a bench by driving a 6-inch spike in the north root of a culebra tree 6 inches in diameter.

Our line from bench No. 16 to bench No. 17 follows the north bank of the river to Stuart's station 210, and then follows very closely the line of his cut-off, west till it meets the river again.

In passing over this ground our maximum elevation was 127.2 feet.

Between bench No. 16 and bench No. 17 backsights were read first by instrument No. 1 and foresights first by instrument No. 3.


Rio Savalos
House
Stuart's bench Nail in north east root of Jobo tree 3' diam.
PRECISE LEVEL BENCH
No17
0 400 800
SCALE
Isla Savalos
RIO SAN JUAN
Toro Rapids
Creek
200'
N
Permanent Bench No17
S 32W 87'
Temporary Bench No17 is 6" spike driven in the south east root of a Guava tree at the surface of the ground. The tree is double. The west part is 2' in diam. The east is 18". The spike is in the east part. The tree is 50' from the river, and at the east end of the first hill below the Rio Savalos.

PRECISE LEVEL BENCH No. 17.

	Mean Elevation above Sea Level.	
Temporary Bench No. 17	31.1376 m.	102.157 ft.
Permanent Bench No. 17, on spike	41.6057 m.	136.501 ft.
Permanent Bench No. 17, highest part stone	41.5967 m.	136.472 ft.
Stuart's Bench on west bank of Savalos	31.6087 m.	103.703 ft.
6" spike in Chaperna tree, Rio Negro	31.7032 m.	104.013 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 17	31.1335 m.	102.144 ft.	31.1416 m.	102.170 ft.
Permanent Bench No. 17, on spike	41.6009 m.	136.486 ft.	41.6104 m.	136.517 ft.
Permanent Bench No. 17, highest part stone	41.5919 m.	136.456 ft.	41.6014 m.	136.487 ft.
Stuart's Bench on west bank of Savalos	31.6030 m.	103.684 ft.	31.6143 m.	103.721 ft.
6-inch spike in Chaperna tree, Rio Negro	31.7002 m.	104.003 ft.	31.7061 m.	104.022 ft.

Bench No. 17 is 7.2 miles by our line beyond bench No. 16, and is on the first hill below the Savalos river.

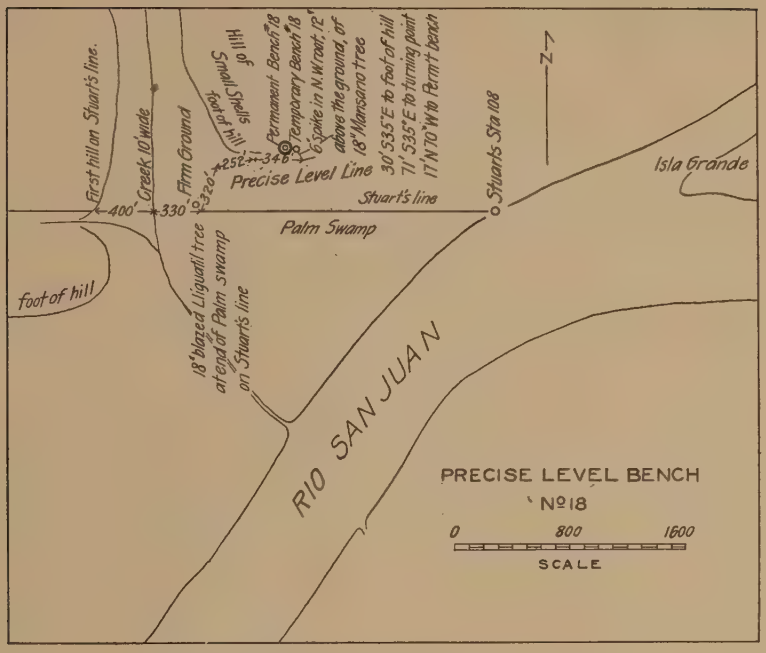
Temporary bench No. 17 is a 6-inch spike driven in the southeast root of a guava tree, 50 feet from the river, and at the east end of the hill.

Permanent bench No. 17 is 71 feet N. 20° E. from the temporary bench. It is a spike set with sulphur in a stone buried 12 inches below the surface. Elevations were taken on the spike and on the highest part of the stone. This bench was made August 19th, and elevations were taken by instrument No. 1 August 26th, and by instrument No. 3 August 19.

There is a bench made by Stuart's party on the west bank of the Savalos river, 20 feet from the San Juan river. It is a nail in the northeast root of a jobo tree, 3 feet in diameter, and is 12 inches above the ground.

We made a bench on the west bank of the Rio Negro about 500 feet from its mouth by driving a 6-inch spike in the south root of a chaperna tree, 12 inches above the ground. The tree is 3 feet in diameter.

From bench No. 16 to bench No. 17 our line is from 500 to 1000 feet back from the north bank of the river. Foresights were read first by instrument No. 1 and backsights first by instrument No. 3.



PRECISE LEVEL BENCH No. 18.

	Mean Elevation above Sea Level.	
Temporary Bench No. 18	36.4926 m.	119.726 ft.
Permanent Bench No. 18, on spike	36.9888 m.	121.354 ft.
Permanent Bench No. 18, on stone	36.9629 m.	121.269 ft.
6″ spike in Jobo tree, Caño Ursula	31.8600 m.	104.527 ft.
6″ spike in Ojocha tree, Palo de Arco Creek	32.7475 m.	107.439 ft.

	Instrument No. 1.		Instrument No. 3.	
Permanent Bench No. 18, on spike	36.9914 m.	121.363 ft.	36.9862 m.	121.346 ft.
6-inch spike in Ojocha tree, Palo de Arco Creek	32.7503 m.	107.448 ft.	32.7447 m.	107.430 ft.

Bench No. 18 is 12.3 miles by our line beyond bench No. 17, and is near the east end of Stuart's cut-off from Isla Grande west.

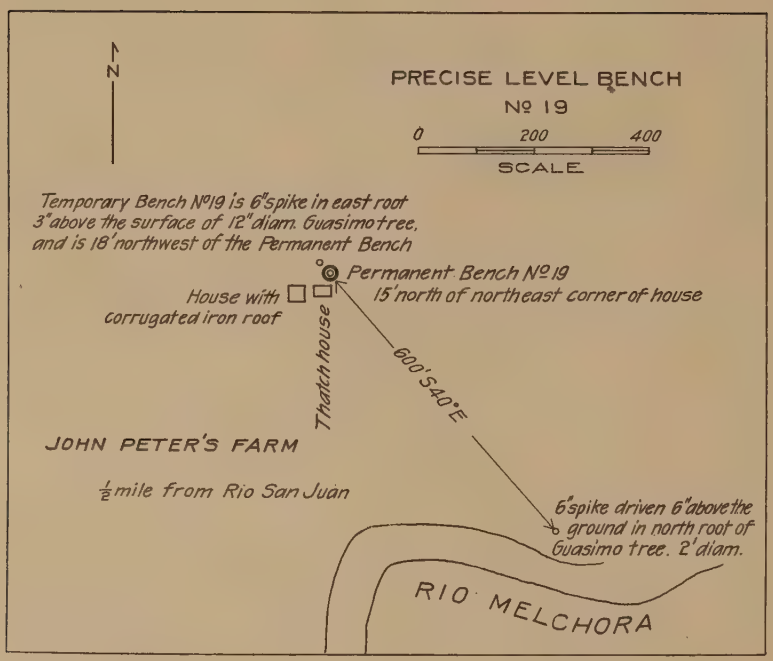
Temporary bench No. 18 is a 6-inch spike, 12 inches above the ground in the northwest root of an 18-inch diameter mansano tree, marked by a blaze 4 feet high and 1 foot wide.

Permanent bench No. 18 is a spike set with sulphur in a stone buried 2 feet below the surface, 17 feet west of the temporary bench. This bench was made September 13th and elevations were taken on the spike, and on the stone at the west side of the spike, by instrument No. 1 September 14th, and by instrument No. 3 September 13th.

On the west bank of the Caño Ursula, about 1000 feet from the San Juan river and 1750 feet above the west end of Stuart's cut-off, we made a bench by driving a 6-inch spike in the northeast root of a jobo tree 3 feet in diameter. This bench is 12 inches above the ground.

125 feet west of the west bank of the Palo de Arco creek and 2000 feet from the San Juan river we made a bench by driving a 6-inch spike in the south root of an ojocha tree. This tree is 3 feet in diameter and has large spreading roots. The bench is 15 inches above the ground.

Between bench No. 18 and bench No. 19 backsights were read first by instrument No. 1 and foresights first by instrument No. 3.


N
PRECISE LEVEL BENCH
Nº 19
0 200 400
SCALE
Temporary Bench Nº19 is 6"spike in east root 3"above the surface of 12"diam. Guasimo tree, and is 18'northwest of the Permanent Bench
Permanent Bench Nº 19
15'north of northeast corner of house
House with corrugated iron roof
Thatch house
600'S40°E
JOHN PETER'S FARM
½ mile from Rio San Juan
6"spike driven 6"above the ground in north root of Guasimo tree. 2'diam.
RIO MELCHORA

PRECISE LEVEL BENCH No. 19.

	Mean Elevation above Sea Level	
Temporary Bench No. 19	39.8534 m.	130.752 ft.
Permanent Bench No. 19, on spike	39.4572 m.	129.452 ft.
Permanent Bench No. 19, on stone	39.4424 m.	129.404 ft.
Spike in Guasimo tree, Melchora River	32.3579 m.	106.161 ft.
Highest part of stone, Melchorito River	32.9975 m.	108.259 ft.
6" spike near Isla Caño	32.1703 m.	105.545 ft.
Stuart's Bench near his Sta. No. 14	32.8219 m.	107.683 ft.

	Instrument No. 1.		Instrument No. 3.	
Permanent Bench No. 19, on spike	39.4580 m.	129.455 ft.	39.4564 m.	129.450 ft
Stuart's Bench near his Station No. 14	32.8225 m.	107.685 ft.	32.8213 m.	107.681 ft.

Bench No. 19 is 7.3 miles beyond bench No. 18.

Temporary bench No. 19 is a 6-inch spike in the east root, 3 inches above the ground, of a 12-inch diameter guasimo tree.

Permanent bench No. 19 is a spike set with sulphur in a stone buried 2 feet below the surface. This bench was made September 21st, and elevations were taken on the spike and on the stone at the side of the spike by instrument No. 1 September 23rd, and by instrument No. 3 September 22nd.

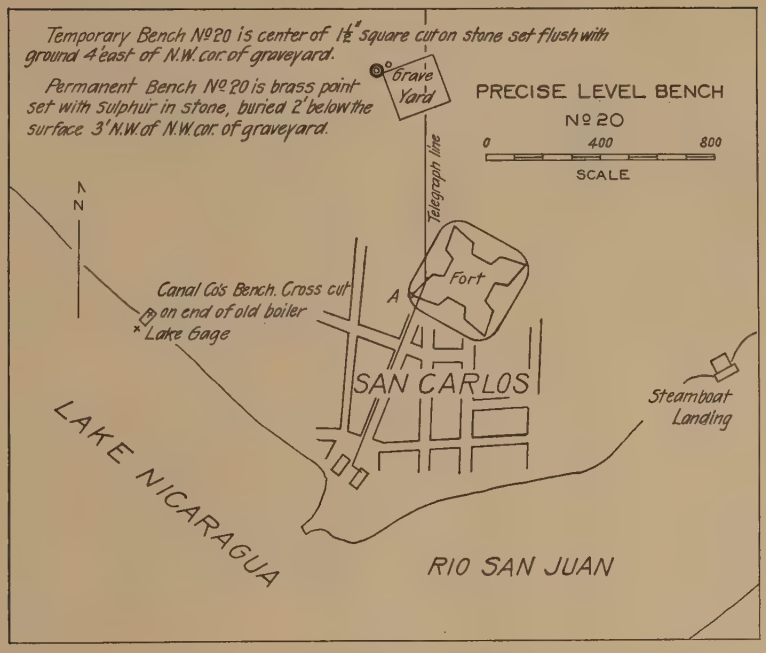
600 feet S. 40° E. from the permanent bench, we made a bench by driving a spike in the root of a guasimo tree on the bank of the Melchora river.

500 feet east of the mouth of the Melchorito river, at the base of a hill about a mile west of the Melchora river, and 25 feet west of an 18-inch jobo tree, marked by a blaze 12 inches by 3 feet, we made a bench by cutting a 3-inch square round the highest part of a large rock.

2000 feet west of the east end of Isla Caño, on the west bank of a creek, and 50 feet from the San Juan river, we make a bench by driving a 6-inch spike in the west root, 2 feet above the ground, of an 18-inch diameter popojonh tree.

We read on Stuart's bench 75 feet west of his station No. 14 on the north root of a 2-foot diameter chilati tree on the first small hill on the north bank of the San Juan river, below Lake Nicaragua.

Between bench No. 19 and bench No. 20 foresights were read first by instrument No. 1 and backsights first by instrument No. 3.


Temporary Bench No 20 is center of 1½" square cut on stone set flush with ground 4' east of N.W. cor. of graveyard.
Permanent Bench No 20 is brass point set with sulphur in stone, buried 2' below the surface 3' N.W. of N.W. cor. of graveyard.
Grave Yard
PRECISE LEVEL BENCH
No 20
0
400
800
SCALE
Telegraph line
N
Canal Co's Bench. Cross cut on end of old boiler
Lake Gage
A
Fort
SAN CARLOS
Steamboat Landing
LAKE NICARAGUA
RIO SAN JUAN

PRECISE LEVEL BENCH No. 20.

	Mean Elevation above Sea Level.	
Temporary Bench No. 20	50.0167 m.	164.096 ft.
Permanent Bench No. 20, on brass	49.0300 m.	160.859 ft.
Permanent Bench No. 20, on stone	49.0070 m.	160.784 ft.
Canal Co.'s Bench on boiler at San Carlos	33.3195 m.	109.316 ft.
13′ mark on gage rod at boiler	33.3561 m.	109.436 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 20	50.0129 m.	164.084 ft.	50.0205 m.	164.109 ft.
Permanent Bench No. 20, on brass	49.0261 m.	160.846 ft.	49.0339 m.	160.872 ft.
Permanent Bench No. 20, on stone	49.0034 m.	160.772 ft.	49.0105 m.	160.795 ft.
Canal Company's Bench on boiler at San Carlos	33.3197 m.	109.316 ft.	33.3193 m.	109.315 ft.
13-foot mark on gage rod at boiler	33.3549 m.	109.432 ft.	33.3572 m.	109.439 ft.

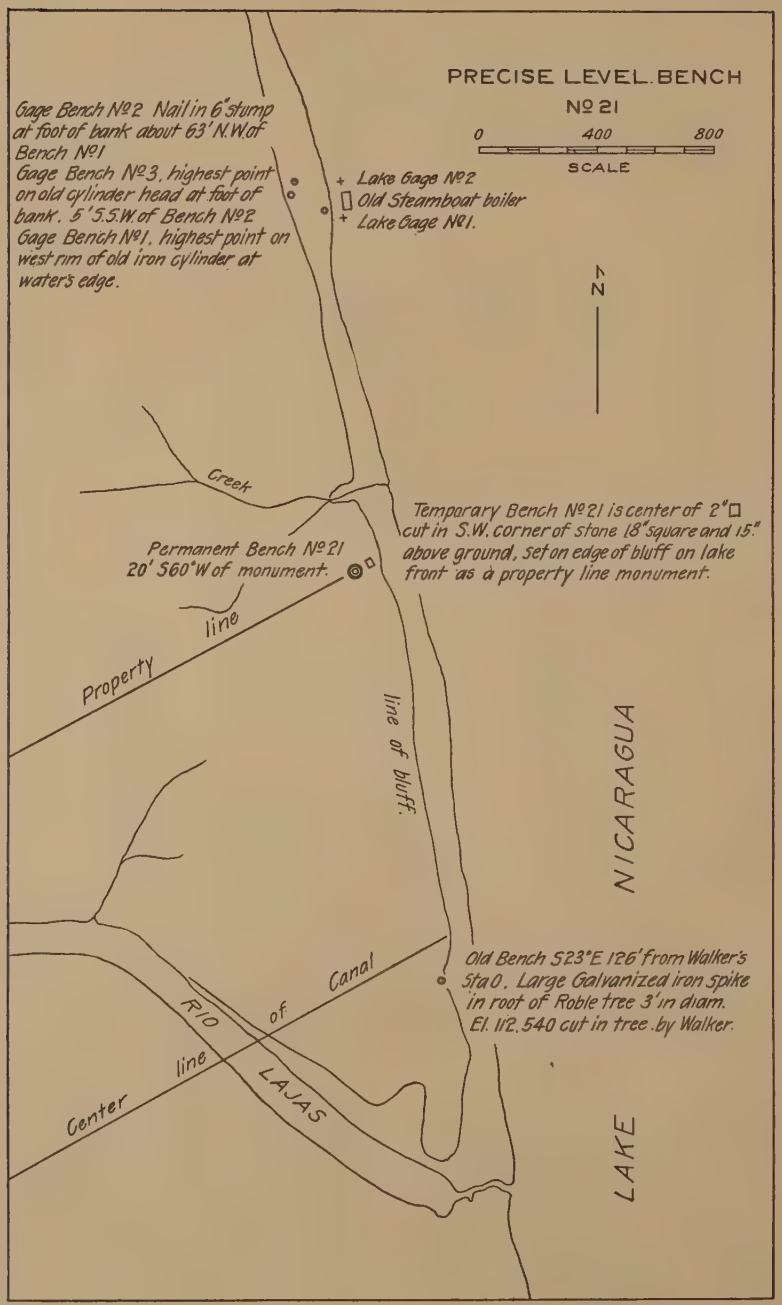
Bench No. 20 is 10.7 miles by our line beyond bench No. 19, and is at the northwest corner of the graveyard at San Carlos, Lake Nicaragua.

Temporary bench No. 20 is the center of a 1½-inch square cut on a stone set flush with the ground, 4 feet east of the northwest corner of the graveyard. Permanent bench No. 20 is a brass point set with sulphur in a stone buried 2 feet below the surface, 3 feet northwest of the northwest corner of the graveyard.

Elevations were taken on the brass point and on the center of a 2-inch square cut in the stone east of the brass point. The stone was placed October 3rd, 1898, and the elevations were taken October 8th.

There is a Canal Company's bench, a cross cut on the shore end of an old steamboat boiler in Lake Nicaragua, southwest of our bench No. 20. This was the initial bench for Stuart's levels.

Southwest of this bench and attached to the iron-work of the old steamboat is the San Carlos lake gage.


PRECISE LEVEL. BENCH
Nº 21
0 400 800
SCALE
Gage Bench Nº 2 Nail in 6" stump at foot of bank about 63' N.W. of Bench Nº 1
Gage Bench Nº 3, highest point on old cylinder head at foot of bank, 5' S.S.W. of Bench Nº 2
Gage Bench Nº 1, highest point on west rim of old iron cylinder at water's edge.
+ Lake Gage Nº 2
Old Steamboat boiler
+ Lake Gage Nº 1.
N
Creek
Temporary Bench Nº 21 is center of 2" □ cut in S.W. corner of stone 18" square and 15" above ground, set on edge of bluff on lake front as a property line monument.
Permanent Bench Nº 21 20' 56° W of monument.
Property line
line of bluff.
NICARAGUA
Old Bench S 23° E 126' from Walker's Sta 0. Large Galvanized iron spike in root of Roble tree 3' in diam. El. 112.540 cut in tree by Walker.
Canal
Rio
of
Center line
LAJAS
LAKE

PRECISE LEVEL BENCH No. 21.

	Mean Elevation above Sea Level.	
Temporary Bench No. 21	37.4572 m.	122.891 ft.
Permanent Bench No. 21, on spike	36.8077 m.	120.760 ft.
Permanent Bench No. 21, on stone	36.7942 m.	120.716 ft.
Lake Gage Bench No. 1	33.1299 m.	108.694 ft.
Lake Gage Bench No. 2	34.5151 m.	113.238 ft.
Lake Gage Bench No. 3	34.3492 m.	112.694 ft.
10′ mark, gage No. I	32.9320 m.	108.044 ft.
9′ mark, gage No. II	31.4520 m.	103.189 ft.
Walker's Bench near his Sta. 0	34.2022 m.	112.212 ft.
Mark on property line stone, San Pablo	39.7240 m.	130.328 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 21	37.4534 m.	122.878 ft.	37.4610 m.	122.903 ft.
Permanent Bench No. 21, on spike	36.8044 m.	120.749 ft.	36.8109 m.	120.770 ft.
Permanent Bench No. 21, on stone	36.7904 m.	120.703 ft.	36.7979 m.	120.728 ft.
Lake Gage Bench No. 1	33.1271 m.	108.685 ft.	33.1326 m.	108.703 ft.
Lake Gage Bench No. 2	34.5122 m.	113.229 ft.	34.5180 m.	113.248 ft.
Lake Gage Bench No. 3	34.3468 m.	112.686 ft.	34.3515 m.	112.702 ft.
10-foot mark, Gage No. I	32.9280 m.	108.031 ft.	32.9359 m.	108.057 ft.
9-foot mark, Gage No. II	31.4508 m.	103.185 ft.	31.4531 m.	103.192 ft.
Walker's Bench near his Station 0	34.1975 m.	112.196 ft.	34.2069 m.	112.227 ft.
Mark on property line stone, San Pablo	39.7208 m.	130 317 ft.	39.7271 m.	130.338 ft.

Bench No. 21 is on the west shore of Lake Nicaragua near the mouth of the Lajas river, and is on the lake end of the Canal Company's north property line, and 1250 feet from the center line of the canal.

Temporary bench No. 21 is the center of a 2-inch square cut in the southwest corner of a stone 18 inches square and 15 inches above ground, set on the edge of the bluff on the lake front as a property line monument.

Permanent bench No. 21 is 20 feet southwest of the temporary bench, and is a spike set with sulphur in a stone buried 18 inches below the surface. Elevations were taken on the spike, and on the center of a 1½-inch square cut in the stone 2 inches northeast of the spike. The bench was made October 20th and readings were taken by instrument No. 1 October 22nd, and by instrument No. 3 October 21st.

About 1200 feet north of our No. 21 bench is the Lajas hydrographic station. There are at this station 3 benches and two gage rods placed to ascertain the height of the lake. Gage bench No. 1 is the highest point on the west rim of an old iron cylinder at the water's edge.

Gage bench No. 2 is about 63 feet northwest of gage bench No. 1, and is a nail in a 6-inch stump at the foot of the bank.

Gage bench No. 3 is 5 feet S. S. W. of gage bench No. 2, and is the highest point on an old cylinder head at the foot of the bank.

Lake gage No. I is attached to the ironwork of the old steamboat, south of the boiler. It is inclined 2 inches to the foot. This gage is used in reading the water during the high stage of the lake.

Lake gage No. II is attached to the ironwork of the old steamboat north of the boiler. This gage is used in reading the water during the low stage of the lake.

There is a bench on the lake front made by Mr. Walker, 126 feet S. 23° E. from his station 0. It is a galvanized iron spike in the root of a roble tree 3 feet in diameter. The elevation 112.540 feet is cut in the tree.

We made a bench on the property line stone near San Pablo. This bench is the center of a square cut in the east corner of the property line stone. The stone is 18 inches square and is 12 inches above the ground. It is on the south side of the road from San Pablo to Rivas, and is 1600 feet from San Pablo.

Our line from bench No. 21 to bench No. 22 follows approximately the Canal Company's north property line to the property line stone at San Pablo, and then follows the Canal Company's center line of the canal. Our maximum elevation west of the lake was 158.8 feet.

Between these benches, foresights were read first by instrument No. 1, and backsights by instrument No. 3.

Elevations were carried across the lake from San Carlos to Las Lajas by comparing the readings of the lake gages at those places.

For carrying the levels across the lake, we have the readings of the gages at San Carlos and Las Lajas during the months of April, May, June, July, August and September. At San Carlos there was one gage bolted to the iron work of an old steamboat. At Las Lajas there were two gages secured to the iron work of another old steamboat. One of these, gage No. I, was read during the high water from April 1st to May 21st, and from July 16 to September 29th. The other, gage No. II, was read during low water from May 1st to July 16th.

Carrying the levels across the lake, using gage No. I at Las Lajas, we find the average height of the water on the San Carlos gage when the readings were taken on the No. I Las Lajas gage to be 7.418 feet, or 5.582 feet below the 13-foot mark, and the average reading on the Las Lajas No. I gage for the same time to be 5.880 feet, or 4.120 feet measured on the gage from the 10-foot mark. Gage No. 1 at Las Lajas, in order that it might be more securely fastened to the boiler, was placed at an inclination of 2 inches to the foot, and reducing 4.120 feet to a vertical distance, it becomes 4.062 feet.

Assuming the average surface of the lake to be level, this shows that the 13-foot mark on the San Carlos rod was 1.520 feet higher than the 10-foot mark on the Las Lajas rod, making the elevation of the 10-foot mark 107.916 feet, and the elevation of the Las Lajas gage bench No. I, 108.566 feet.

Comparing the readings of gage No. II at Las Lajas and the San Carlos gage, and assuming the average surface of the lake to be level while these readings were taken, we find the average difference between the readings shows the zero of the No. II gage to be 2.247 feet below the zero of the San Carlos gage, and the elevation of the 9-foot mark on the No. II Las Lajas gage to be 103.189 feet, and the elevation of the Las Lajas gage bench No. I to be 108.694 feet.

Taking the average of the five calm days selected by Mr. Davis for comparing all the lake gages, and using No. II gage reading at Las Lajas, gives the elevation of the 9-foot mark 103.233 feet, and of the Las Lajas gage bench No. 1, 108.737 feet. The Canal Company's bench on the boiler at San Carlos is then shown to be higher than No. I gage bench, if we use—

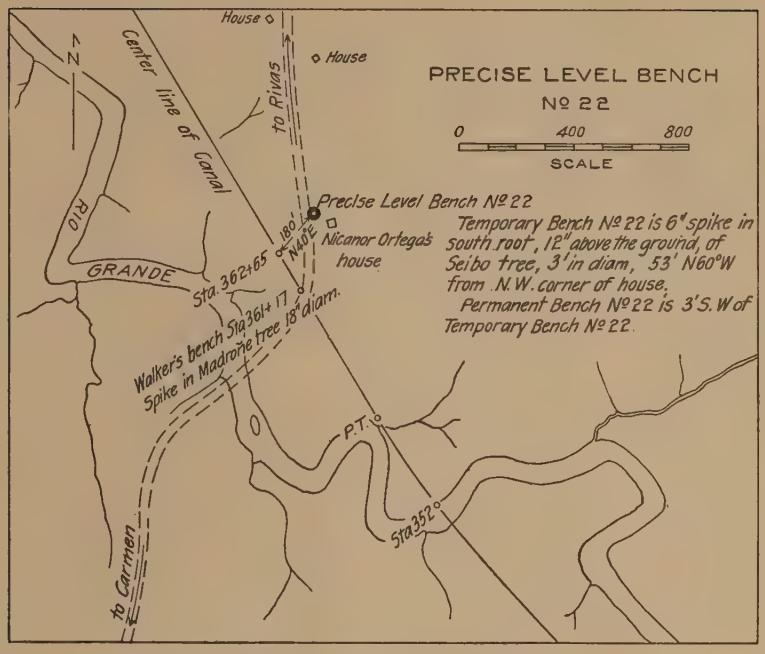
No. I gage, average of all readings..	.750 feet.
" II gage, average of all readings..	.622 feet.
" II gage, 5 selected days.....	.579 feet.
Canal Company's figures.....	.728 feet.

Levels were carried across the lake by the Canal Company, and connecting their levels with No. I gage bench gives the last figure.

We have used the results obtained from an average of all the readings on gage No. II, giving the elevation of gage bench No. I as 108.694 feet.

The readings on gage No. I were taken when the lake was discharging the maximum amount of water, and when there was a strong east wind blowing, and these causes may have made the west side of the lake 1½ inches higher than the east, as the gages seemed to show.

No. II gage was read during the calmest period of the year, and when the discharge of the lake was least. The result we use is the average of the readings for 77 days, 5 readings being taken each day. The five selected days hardly give enough readings to calculate an average condition of the lake as closely as we obtain by taking all the readings of No. II gage.



PRECISE LEVEL BENCH No. 22.

	Mean Elevation above Sea Level.	
Temporary Bench No. 22	44.1266 m.	144.772 ft.
Permanent Bench No. 22, on spike	42.9646 m.	140.960 ft.
Permanent Bench No. 22, on stone	42.9428 m.	140.888 ft.
Walker's Bench at his Sta. 361+17	35.2113 m.	115.522 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 22	44.1247 m.	144.766 ft.	44.1284 m.	144.778 ft.
Permanent Bench No. 22, on spike	42.9633 m.	140.955 ft.	42.9659 m.	140.964 ft.
Permanent Bench No. 22, on stone	42.9416 m.	140.884 ft.	42.9439 m.	140.892 ft.
Walker's Bench near his Station 361 + 17	35.2102 m.	115.519 ft.	35.2123 m.	115.526 ft.

Bench No. 22 is 7.6 miles by our line beyond bench No. 21, and is near Nicanor Ortega's house on the road from Rivas to Carmen, just north of the Rio Grande.

Temporary bench No. 22 is a 6-inch spike in the south root, 12 inches above the ground, of a seibo tree 3 feet in diameter.

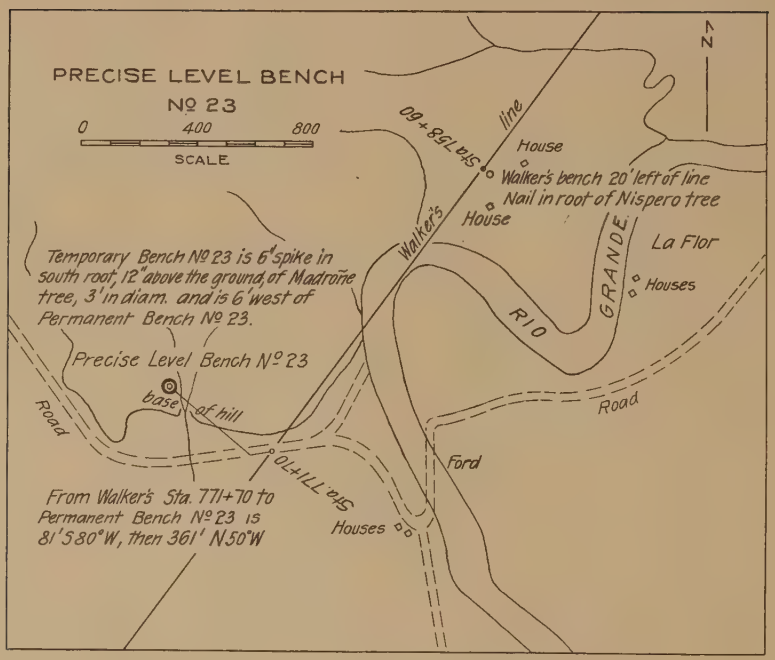
Permanent bench No. 22 is 3 feet southwest of the temporary bench, and is a spike set with sulphur in a stone buried 3 feet below the surface. Elevations were taken on the spike and on the center of a 1½-inch square cut in the stone 3 inches west of the spike.

The bench was made October 26th and elevations were taken by instrument No. 1 October 27th, and by instrument No. 3 October 26th.

About 300 feet south of our bench is a bench made by Mr. Walker at his station 361 + 17. This bench is a spike in a madroñe tree 18 inches in diameter.

Between benches 22 and 23 our line follows approximately the Canal Company's center line for the canal.

Between these benches backsights were read first by instrument No. 1, and foresights first by instrument No. 3.



PRECISE LEVEL BENCH No. 23.

	Mean Elevation above Sea Level.	
Temporary Bench No. 23	15.3642 m.	50.407 ft.
Permanent Bench No. 23, on spike	14.4431 m.	47.385 ft.
Permanent Bench No. 23, on stone	14.4317 m.	47.348 ft.
Walker's Bench 20′ left of his Sta. 758+60	14.8104 m.	48.590 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 23	15.3665 m.	50.415 ft.	15.3618 m.	50.400 ft.
Permanent Bench No. 23, on spike	14.4454 m.	47.393 ft.	14.4406 m.	47.377 ft.
Permanent Bench No. 23, on stone	14.4341 m.	47.356 ft.	14.4293 m.	47.340 ft.
Walker's Bench, 20 feet left of his Station 758 + 60	14.8133 m.	48.600 ft.	14.8075 m.	48.581 ft.

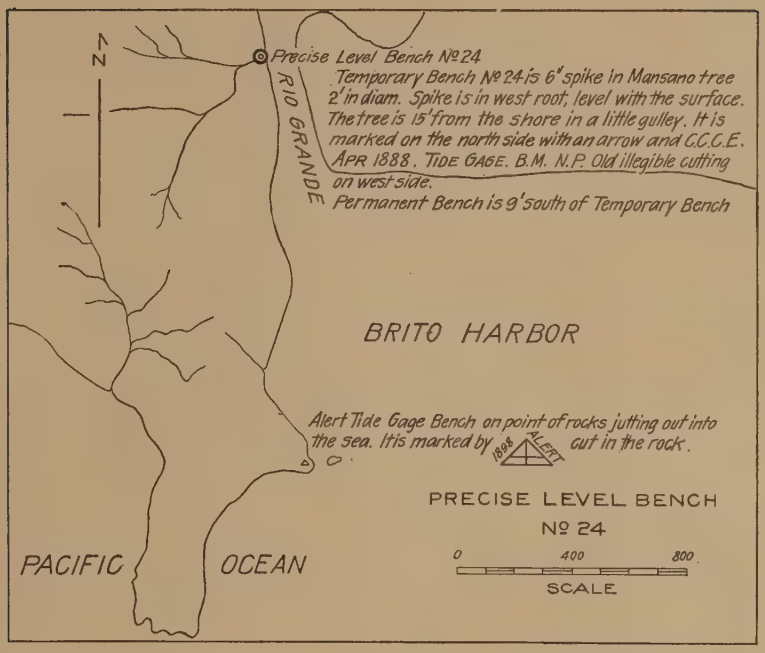
Bench No. 23 is 8.6 miles by our line beyond bench No. 22. It is on the first hill east of the Pacific on the Canal Company's center line of the canal, and is near the proposed La Flor dam, and about 400 feet right of Walker's station 772.

Temporary bench No. 23 is a 6-inch spike in the south root, 12 inches above the ground, of a madroñe tree 3 feet in diameter.

Permanent bench No. 23 is 6 feet east of the temporary bench, and is a spike set with sulphur in a stone buried 18 inches below the surface. Elevations were taken on the spike and on the center of a 1½-inch square cut in the stone, 2 inches south of the spike. The bench was made October 31st and elevations were taken November 1st.

About 1400 feet northwest of bench No. 23 is a bench made by Mr. Walker 20 feet left of his station 758 + 60. This bench is a nail in the root of a nispero tree.

Our line from bench No. 23 to bench No. 24 follows the north bank of the Rio Grande. Between these benches foresights were read first by instrument No. 1, and backsights first by instrument No. 3.


N
Precise Level Bench No 24
Temporary Bench No 24 is 6" spike in Mansano tree 2' in diam. Spike is in west root, level with the surface. The tree is 15' from the shore in a little gulley. It is marked on the north side with an arrow and C.C.C.E. Apr 1888. Tide Gage. B.M. N.P. Old illegible cutting on west side.
Permanent Bench is 9' south of Temporary Bench
RIO GRANDE
BRITO HARBOR
Alert Tide Gage Bench on point of rocks jutting out into the sea. It is marked by 1898 ALERT cut in the rock.
PRECISE LEVEL BENCH
No 24
0 400 800
SCALE
PACIFIC OCEAN

PRECISE LEVEL BENCH No. 24.

	Mean Elevation above Sea Level.	
Temporary Bench No. 24	2.8380 m.	9.311 ft.
Permanent Bench No. 24, on spike	3.0956 m.	10.156 ft.
Permanent Bench No. 24, on stone	3.0785 m.	10.100 ft.
"Alert" Bench	3.6366 m.	11.931 ft.

	Instrument No. 1.		Instrument No. 3.	
Temporary Bench No. 24	2.8386 m.	9.313 ft.	2.8374 m.	9.309 ft.
Permanent Bench No. 24, on spike	3.0957 m.	10.156 ft.	3.0955 m.	10.156 ft.
Permanent Bench No. 24, on stone	3.0787 m.	10.101 ft.	3.0782 m.	10.099 ft.
"Alert" Bench	3.6357 m.	11.928 ft.	3.6374 m.	11.934 ft.

Bench No. 24 is at the mouth of the Rio Grande, on the west bank.

Temporary bench No. 24 is a 6-inch spike in a mansano tree 2 feet in diameter. The spike is in the west root, level with the surface. The tree is 15 feet from the edge of the water in a little gully. It is marked on the north side with an arrow and "C. C. C. E. April 1888. Tide gage B. M. N. P." There is an old illegible cutting on the west side.

Permanent bench No. 24 is 9 feet south of the temporary bench. It is a spike set with sulphur in a stone buried 1 foot below the surface. Elevations were taken on the spike and on a 1½-inch square cut in the stone 2 inches north of the spike. The bench was made November 1st and elevations were taken November 2nd, 1898.

The bench to which the Brito tide gagings were referred is about 1500 feet south of our bench No. 24, and is on a point of rocks jutting out into the sea. It is marked by a triangle and cross lines, and "Alert, 1898."

The tide gagings at Brito were made by the officers of the U. S. S. Alert. Two gages were used, one called the outer gage, the other the inner. Both gages were connected by the Alert people with their bench at Brito, and the mean daily sea level, for each day the gages were read, has been found by plotting the readings just as was done with the Greytown tide gage readings. The outer gage was often disturbed by the violence of the waves, and had to be reconnected with the bench, while the inner gage remained at one height during all the readings. These daily mean sea level values were then plotted as ordinates, the line joining their extremities showing the variation of mean daily sea level.

For the outer gage we have 29 mean daily sea level values between February 16th and March 21st, 1898, and the average of these values shows mean sea level to be 12.856 feet below the Alert bench mark.

For the inner gage we have 49 mean daily sea level values between February 19th and April 8th, and the average of these values shows mean sea level to be 12.886 feet below the Alert bench mark.

Mean sea level values for the inner gage during a selected period of 29 days show mean sea level to be 12.901 feet below the Alert bench mark.

Taking 12.886 feet the average of all the readings on the inner gage as probably nearest right, this shows mean Pacific sea level at the time these readings were taken to be .995 foot below mean Atlantic sea level. The Canal Company's Pacific mean sea level is .328 foot below mean Atlantic sea level.

The Alert Brito tide gage readings did not extend over a long enough period to determine accurately the mean level of the Pacific ocean, as the monthly variation of the mean height of the ocean in this locality is considerable.

The tide tables published by the Coast Survey show that at Panama, during the period when these readings were taken, the sea was one foot below the normal, and if this was also the case at Brito, our levels show mean sea level for the two oceans to be the same.

The highest high tide observed by the Alert people was 4.9 feet above the mean level of the Pacific ocean as given by the Alert gages, or 3.9 feet above mean Atlantic sea level.

The lowest low tide was 4.4 feet below the mean level of the Pacific ocean as given by the Alert gages, or 5.4 feet below mean Atlantic sea level, the extreme range of the tide being 9.3 feet.

The mean of the daily highest water elevations was 3.42 feet above the mean level of the Pacific ocean as given by the Alert gages, or 2.46 feet above mean Atlantic sea level.

The mean of the daily lowest water elevations was 3.38 feet below the mean level of the Pacific ocean as given by the Alert gages, or 4.34 feet below mean Atlantic sea level.

The mean of all high tides was 3.15 feet above the mean level of the Pacific ocean as given by the Alert gages, or 2.19 feet above mean Atlantic sea level.

The mean of all low tides was 3.13 feet below the mean level of the Pacific ocean as given by the Alert gages, or 4.09 feet below mean Atlantic sea level.

COMPARISON OF PRECISE LEVEL ELEVATIONS WITH ELEVATIONS GIVEN BY H. H. TRUNDLE AND BY THE CANAL COMPANY BETWEEN GREYTOWN AND OCHOA.

All the elevations are given in feet.

	Elevations from Trundle's field notes, corrected to agree with precise level field elevations.	Elevations from Trundle's field notes, with corrections taken out, and Canal Co.'s elevations.	Elevations reduced to mean sea level by the addition of .520 ft.	Difference.	Precise level elevations.	Precise level Instrument No. 1.	Precise level Instrument No. 3.
Canal Co.'s bench in machine shop near Greytown	4.538	4.538	5.058	.000	5.058	5.044	5.072
Track spike on north side of north rail at Sta. 85	8.422	8.422	8.942	+.026	8.916	8.941	8.891
Track spike on north side of north rail at Sta. 112	7.243	7.243	7.763	—.142	7.905	7.931	7.878
Track spike on north side of north rail at Sta. 174	9.449	9.449	9.969	—.196	10.165	10.210	10.120
Track Spike at Sta. 216	12.611	12.611	13.131	—.193	13.324	13.374	13.274
Track spike at Sta. 224 (P. L. bench No. 4 is near Sta. 232)	14.426	14.426	14.946	—.262	15.208	15.258	.....
Track spike on south side of south rail at Sta. 251+36	11.304	11.304	11.824	—.255	12.079	12.125	12.033
Nail in root of stump 40 ft. L. of Sta. 406+30	15.370	15.370	15.890	—.310	16.200	16.224	.....
Track spike north side of north rail at Sta. 500+03	20.978	20.978	21.498	—.387	21.885	21.903	21.867
Precise level bench No. 4 on glass	24.195	24.195	24.715	—.175	24.890	24.913	24.866
Nail in root of old 18″ stump 16.5′ L. of Sta. 587+12.5	26.197	26.197	26.717	—.185	26.902	26.910	26.895
Precise level bench No. 5 on glass	93.992	93.772	94.292	—.065	94.357	94.366	94.349
Nail in root of 18″ tree 400′ L. of Sta. 723+60	41.089	40.950	41.470	—.255	41.725	41.716	41.734
Canal Co.'s copper bolt in root of tree 100′ right of Sta. 806 on north bank of Rio Deseado — Trundle's elev.	58.316	58.177	58.697	—.453	59.150	59.141	59.158
Canal Co.'s copper bolt in root of tree 100′ right of Sta. 806 on north bank of Rio Deseado — Canal Co.'s elev.	.....	58.420	58.940	—.210	59.150	59.141	59.158
Precise level bench No. 6 on glass	122.200	121.727	122.247	—.486	122.733	122.716	122.750
Nail in root of 30″ almendro tree 65′ L. of Sta. 957+20 on east bank of Caño Limpio near old Camp Alice	246.627	246.154	246.674	—.550	247.224	247.231	247.216
Canal Co.'s copper bolt in stump of redwood tree 14″ dia. near Camp Carmen at Sta. 1047+50 — Trundle's elev.	99.296	98.715	99.235	—.419	99.654	99.686	99.621
Canal Co.'s copper bolt in stump of redwood tree 14″ dia. near Camp Carmen at Sta. 1047+50 — Canal Co.'s 1st elev.	.....	99.727	100.247	+.593	99.654	99.686	99.621
Canal Co.'s copper bolt in stump of redwood tree 14″ dia. near Camp Carmen at Sta. 1047+50 — Canal Co.'s 2d elev.	.....	98.727	99.247	—.407	99.654	99.686	99.621
Precise level bench No. 7 on glass	134.513	133.932	134.452	—.424	134.876	134.904	134.848
Spike in root of 60″ tree at Sta. 1117+80 on east bank of Rio Chanchos	52.129	51.630	52.150	—.369	52.519	52.522	52.516
Nail in 30″ tree on east bank of Rio San Francisco at Hydrographic Station near Sta. 1250	51.107	50.703	51.223	—.345	51.568	51.573	51.563
Canal Co.'s bench 45 ft. right of Sta. 1352, described by Canal Co.'s notes as at Sta. 1352. Blazed tree 15″ dia. No nail in bench. Bench somewhat overgrown with bark. The connection with the precise level line was made by Trundle's party from the San Francisco bench. Canal Co.'s elevation	.....	76.063	76.583	—.025	76.608	.....	.....
Nail in root of large almendro tree on telegraph line about opposite Sta. 1546+75	144.807	144.488	145.008	—.232	145.240	145.263	145.218
Nail in root leaning tree north bank of San Juan river, opposite Hydrographic Camp, and 15′ L. of Sta. 1678+20	71.280	70.961	71.481	—.263	71.744	71.747	71.740

COMPARISON OF PRECISE LEVEL ELEVATIONS WITH ELEVATIONS GIVEN BY F. L. STUART BETWEEN OCHOA AND SAN CARLOS.

Stuart's elevations are taken from the Canal Company's elevation of the bench at San Carlos, which elevation is derived from their Pacific levels.

All the elevations are given in feet.

	Stuart's No. 1 Line.	Stuart's No. 2 Line.	Stuart's mean elevation.	Difference	Precise level elevations.	Precise level Instrum't No. 1.	Precise level Instrum't No. 3.
Spike in north root of cottonwood tree 5 ft. in dia. This tree is 15 ft. from the north bank of the Rio San Juan, near Ochoa telegraph station.	68.41	68.41	68.410	+.069	68.341	68.342	68.341
Nail in root of leaning tree on north bank of San Juan river, opposite Hydrographic Camp and 15 ft. L. of Sta. 1678+12 of Trundle's line, and last bench on that line. Stuart's difference at this point, which is just above Ochoa, is interpolated between +.069 and +.073 proportionately to the distance	.....	.....	71.813	+.070	71.743	71.747	71.740
Stuart's Sta. 604	62.20	62.38	62.290	+.073	62.217	62.211	62.224
" " 592	59.47	59.52	59.495	+.013	59.482	59.462	59.502
" " 590	61.32	61.38	61.350	+.031	61.319	61.297	61.342
" " 588	60.78	60.86	60.820	+.051	60.769	60.741	60.797
" " 584	61.93	62.03	61.980	+.041	61.939	61.921	61.957
" " 578	62.95	.....	62.950	+.043	62.907	62.890	62.924
" " 576	58.97	59.10	59.035	+.105	58.930	58.920	58.940
" " 562	61.45	61.50	61.475	+.026	61.349	61.357	61.340
" " 554	64.37	64.29	64.330	+.117	64.213	64.228	64.202
" " 526	64.04	64.01	64.025	+.081	63.944	63.954	63.935
" " 276	71.46	71.37	71.415	—.043	71.458	71.453	71.462
" " 242	85.20	85.17	85.185	+.042	85.143	85.137	85.149
" " 238	84.27	84.14	84.205	+.043	84.162	84.149	84.175
" " 210	.....	.....	92.760	+.084	92.676	92.661	92.692
Stuart's Bench.—Nail in northeast root of jobo tree, 3 ft. in diameter, on west bank of Rio Savalos	.....	.....	103.590	—.113	103.703	103.684	103.721
Stuart's Bench, 75′ west of his Station, No. 14, on north root of chilati tree, 2 ft. in dia.	.....	.....	107.980	+.313	107.667	107.685	107.681
Canal Co.'s Bench.—Cross cut in north end of old steamboat boiler in lake at San Carlos	.....	.....	109.750	+.434	109.316	109.316	109.315

COMPARISON OF PRECISE LEVEL ELEVATIONS WITH ELEVATIONS GIVEN BY J. W. G. WALKER TAKEN FROM THE CANAL COMPANY'S BENCHES WEST OF LAKE NICARAGUA.

All the elevations are given in feet.

	Elevations given by J. W. G. Walker, taken from Canal Company's Bench near Sta. 0.	Elevations given by J. W. G. Walker taken from Canal Co.'s Bench near Sta. 517+20.	Subtract .328 ft. to reduce to mean Atlantic sea level.	Difference.	Precise level elevations.	Precise level Instrument No. 1.	Precise level Instrument No. 3.
Spike in root of roble tree, 126′ S. E. of Sta. 0	112.540	.....	112.212	.000	112.212	112.196	112.227
Spike in root of roble tree, 126′ S. E. of Sta. 0	.....	112.326	111.998	—.214	112.212	112.196	112.227
Spike in root of madroñe tree at Sta. 361+17	115.815	.....	115.487	—.035	115.522	115.519	115.526
Spike in root of madroñe tree at Sta. 361+17	.....	115.601	115.273	—.249	115.522	115.519	115.526
Spike in nispero tree 20′ L. of Sta. 758+60	.....	48.932	48.604	+.014	48.590	48.600	48.581
Alert tide-gage bench	.....	12.259	11.931	—.000	11.931	11.928	11.934

The preceding tables give a third line of levels from Greytown to Brito. These tables comparing the third line with our line are given to show that there is no possibility of any large error in our work.

The first table gives the levels from Greytown to a bench just above Ochoa. These are the levels of Trundle's party and were run by Dion Martinez with an ordinary Y level. There are also given on this part of the line, three checks with old Canal Company benches, all that we were able to find on this line.

Trundle's levels and our field levels are based on the Canal Company's elevation of the bench in the machine shop near Greytown. The first column gives Trundle's levels as recorded in his field books. These levels were kept with our field levels by correcting them to agree with our levels at eight places. In order to make an independent line, these corrections have been taken out, and the second column gives elevations from Trundle's uncorrected work. In the third column, these elevations have been reduced to mean sea level by the addition of .52 ft.

The fourth column gives the difference between Trundle's levels and ours. The maximum difference is at the highest point at which we compared elevations and is .55 ft. The final difference is .263 ft.

In the half mile between station 85 and station 112 there is a change in the difference of the elevations of .168 ft.

We ran this part of the line over to make sure the mistake was not in our work, and the result differed from our first running by .01 ft. If in this short piece of line which we have rerun, we substitute our running for Trundle's, the maximum difference in our lines is .382 ft. and the final difference is .095 ft.

After leaving Greytown the first Canal Company bench we found was near our bench No. 6, at Camp Warner Miller, where we differ from the Canal Company's elevation by .21 ft.

The next Canal Company bench we found was near our bench No. 7. This bench is not on the Canal Company's original line, the line over which they carried their check levels, but is on a later line run from Chanchos river to Camp Saltos, the first camp east of the divide. This line did not check with the original check leveled line, hence the two sets of elevations. Our elevation comes in between their two elevations, differing .6 ft. from one and .4 ft. from the other.

The next Canal Company bench we found was west of the San Francisco river, where we again meet their through line of levels. Our elevation for this bench differs from theirs by .025 ft. This was the last Canal Company bench we were able to find east of the lake.

At Ochoa we passed Stuart's party working down the river, and were given their elevations for all their stations. These levels were run by S. S. Evans with an ordinary transit in connection with the survey work of the river. They started with the Canal Company's elevation for their bench on the boiler at San Carlos which elevation is derived from their levels west of the lake, so that Stuart's and Walker's levels form a continuous line.

Stuart did not tie to Trundle's line, but tied to our line above and below Trundle's last bench, and by interpolating a difference for this bench, we obtain the result shown, in the table.

From Castillo, down the river, Stuart carried a duplicate line of levels, using the turning points on the north side of the river for one line, and those on the south side for the other, and on this part of the line we check with him very

closely, our maximum difference being one-tenth of a foot. From Castillo to the lake, there is a single line, and as the river in this part of the line runs through swamp and the transit head was set up on sawed off trees standing in the water, we could not expect to check as closely. Our levels at San Carlos differ from Stuart's by .434 ft. which is .361 ft. greater than the difference at Ochoa. We differ from the Canal Company in crossing the lake by .106 ft.

West of the lake we have Walker's levels, run with an ordinary Y level, H. C. Hurd, levelman. These levels start with a Canal Company's bench on the lake and change .214 ft. to agree with the Canal Company benches nearer the Pacific. The maximum difference between our levels and Walker's connection with the nearest Canal Company bench is .035 ft. and at the Alert tide gage bench we agree exactly.

Trundle's elevation for his last bench is 71.481 ft.

Stuart's elevation for this bench is 71.813 feet.

To make Stuart's line and Walker's line continuous with Trundle's, we must deduct from their elevations the difference between 71.813 ft. and 71.481 ft. or .332 ft. which gives for the elevation of the Alert bench at Brito, 11.927 ft. as against 11.931 ft., our mean elevation.

The unit measure used on this combination line was 1 ft. and on our line, 1 meter, so there is no possibility of a unit mistake on one of the lines being balanced by a similar mistake in the other.

The greater part of Trundle's line was run after our line. Stuart's and Walker's lines were run before our line. Trundle's and Walker's lines were run in the same direction as ours. Stuart's in the opposite direction.

Our line from Greytown to Brito was carried over 136 miles of land and 70 miles of water, or 206 miles in all.

By assuming none of the errors in our two lines to be cumulative, or all to be compensating, and to vary as the square root of the distance run, we have found between each two benches the probable error introduced in our mean elevation, and the rate per mile of this error, and from this, the average rate per mile for the whole line.

Determined in this way, .00131 m. (.0043 ft.) was the average rate per mile for the probable error introduced in our mean elevations, and multiplying this rate per mile, by the square root of 136, the number of miles run gave .0153 m. (.0502 ft.) as the probable error in our final elevation introduced in carrying the levels over the land part of the line. Determined in this same way, the average difference between the two lines per mile run, was .00393 m. (.0129 ft.).

The average daily difference between the two lines was .0042 m. (.0138 ft.) and the average daily probable error in our mean elevation was .0014 m. (.0046 ft.). Multiplying this average daily error by the square root of 174 (the number of days we ran), gives .0185 m. (.0607 ft.) as the probable error in our final elevation introduced in carrying the levels over the land part of the line, considering none of the errors to be cumulative.

Very respectfully yours,

STEPHEN HARRIS,
Assistant Engineer.

APPENDIX X

REPORT OF ANDREW ONDERDONK

Assistant Engineer

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APPENDIX X

WASHINGTON, D. C., April 10, 1899.

MR. E. S. WHEELER,

Chief Engineer, Nicaragua Canal Commission, Washington, D. C.

Sir:—I have the honor to submit herewith a report of my work under the Nicaragua Canal Commission, while in Nicaragua, C. A.

After having arrived in that country upon the 18th of December 1897, I received a letter of instructions dated December 21, 1897, stating that I was to take charge of a topographic party for the purpose of making an outline survey of Greytown harbor, and at the same time naming the men that were to constitute the officers of that party. These names are as follows with the rank, to which I assigned them, appended: Wm. G. Fitzgerald, transitman; John Carmichael, levelman; Wm. D. Thomas, rodman; Louis E. Lannan, chainman and Adolfo V. Montes, backflagman.

Actual work was commenced by taking the topography in the vicinity of La Fé. All lines were run by transit and measurements taken with a 100-ft. steel tape or by triangulation. One of the first things done was to establish a base line two miles in length for the use of the Newport hydrographic party. This base line was laid off upon practically level ground and measured twice with a steel tape, the first measurement being made at a temperature of 75° F. and the second at 108° F. After making the correction for temperature the difference in the two measurements was about 2 inches in the 10,500 feet.

The survey was then continued, accurately determining the shore lines of the sea, lagoons and islands between the mouth of Indian river and one mile south of Harbor Head lagoon. This work was completed January 24, 1898, when in accordance with your instructions I continued my survey up the lower San Juan river by means of stadia measurements of courses running generally diagonally from one side of the river to the other, and varying from 400 to 1400 feet in length. The levels were based on the Maritime Canal Company's bench mark in the machine shop near La Fé. They were carried immediately after the transit party, using the transit hubs for turning points. Soundings of the river were taken, as a rule, opposite each transit hub and at right angles to the river. This river work extended for about 12 miles up the lower San Juan river and included the Taura river, which is 4 miles long.

On March 12 in accordance with your further instructions, I broke up camp and reported at headquarters to take charge of the draughting room. This position I retained until leaving Nicaragua on 16th of September. During which time my assistants were Ralph Begien from March 24 to July 15, R. C. Wheeler from April 1, to May 1, Horace F. Collins from May 5 to Sept. 16.

Besides this work, as there was a lack of any

definite information regarding the distance the volcanic sand extends along the seacoast, agreeable to your instructions I made a reconnoissance of the coast in May and June covering a distance of 50 miles southward and 35 miles northward from Greytown, finding this sand at both extremities of my reconnoissance. My report to you upon this subject made in June, 1898, is herewith submitted.

Very Respectfully,

ANDREW ONDERDONK,
Assistant Engineer.

VOLCANIC SAND ALONG THE SEACOAST.

In accordance with your verbal instructions of May 18 to make such investigations along the coast, both northward and southward from the mouth of the Colorado river, as would, at least, tend towards the determination of the amount, extent and direction of the drift of the volcanic sand delivered to the sea through the channels of the San Carlos, San Juan and Colorado rivers, I left Greytown on May 20 in a canoe with two paddlers and ten days' provisions, for my southern trip, taking the following route: Up the lower San Juan river to Pereira creek, down that creek and through a lagoon bearing the same name, to the Colorado river; thence to the mouth of that river at Colorado bar; thence up the river to Simon lagoon; through that lagoon to the seacoast; thence by foot along the beach to Turtle Bogue; thence by canoe through Islote lagoon and Petrel creek to Parasmina; thence up the Reventazon river about two miles. When I had reached this point I concluded that it would be unnecessary to proceed further as I had found the conditions so different from what I had anticipated when I made my meager arrangements for the reconnoissance. I therefore turned back taking the same route homeward as far as Colorado bar, thence I took the sea to Harbor Head; thence by the way of lower San Juan river, Caño de Animas and Greytown lagoon, arriving at Greytown in the afternoon of Saturday, May 28. On June the 1st I started northward walking to the mouth of Indian river, where I hired a canoe. In this canoe I went up the Indian river (stopping over night upon the beach about two miles above the mouth of the river) to Indian creek, through this creek to Haulover lagoon and Spanish creek, from this point I walked along the beach to Point of Rocks, at which point I turned back taking the same route homeward as in going, arriving at headquarters in the afternoon of Sunday, June the 5th.

Accompanying this report is an enlargement of a portion of Luis Friederichsen's map of Costa Rica, corrected from maps of the Nicaragua Canal Commission, 1898, the navigation chart of 1886 and my own notes.

My observations and conclusions are as follows. In the first place, both Simon and Agua Dulce lagoons show evidences that they had been former channels of the Colorado river, giving a range of about twelve miles within which the mouth of that river has shifted. And then at the mouth of Agua Dulce lagoon and again at the mouth of Simon lagoon the banks of the river are composed of hard, compact strata of sand. How much further up the river this sand extends I cannot say but in all probability, for several miles, and for an even greater distance on either side of the river, making it possible that the river mouth at one time was anywhere between the vicinity of Greytown and that of Turtle Bogue, thus rendering it difficult to determine which way the sand has drifted since it was delivered to the sea or even what river made the delivery. I found at Islote

Point the same stratum of compact sand that is exposed in the banks of the Colorado river. I also found the same character of sand in the bottom of Petrel creek, in the bottom of California river and in shoals on the convex side of the bends in the Reventazon river. Besides this I was told that this same sand was to be found as far up the Reventazon river as its junction with the Parasmina river and that the bottom of that river was composed of round boulders varying in size from that of a hen's egg on up to a much greater size. Upon examining some boulders found at the mouth of the Reventazon river answering to the description given of those in Parasmina river, they appeared to be composed of the same material as that of the volcanic sand in question, which seems to indicate that other rivers having their source in the same volcanic region as the San Carlos, have been and still are bringing sand to the coast, besides the Colorado.

As far south as Parasmina there is no apparent diminution of sand from that between Harbor Head and Colorado bar, but it is much lighter in color and finer in grain, bearing a closer resemblance to that found north of Indian river, but it is not so light and fine as that found north of Spanish creek. This peculiarity might indicate that it had drifted for some distance and had lost its larger and darker particles, which is evidently the case with the sand north of Spanish creek. In the vicinity of Greytown, owing to the peculiar conformation of the shore, the greatest deposit of sand occurs, within the 85 miles of coast that my reconnoissance covered. This deposit or at least the greater part of it is from the sand delivered to the coast through the channels of the San Juan river delta, as may be verified by its identification with that found in the San Juan river, both as to its color and its coarseness, and by its dissimilarity in those respects to the sand found in other vicinities. That any of the San Juan river sand has drifted southward was not apparent, but all the evidence indicates that the general movement of the sand is to the northward. In the vicinity of Greytown this is apparent. At Colorado bar the shore is being washed away on the north, and is filling up on the south side of the river. At Turtle Bogue we have the same conditions. About a year ago about three-quarters of a mile of the tongue of land at that place was washed away by a river freshet and the two islands or shoals, shown upon the map, were formed in the early part of last month. At Parasmina again we have the same building up of the shore on the south side of the mouth of the Reventazon river, if not the washing away of the north side. In regard to what has taken place previously, the indications are that the mouth of the California river if not also that of the Reventazon river, was at Haulover forming a long tongue of land pointing northward, the natural results of a northward drift of sand at the mouth of a river. At Turtle Bogue we have a similar tongue of land pointing northward, and there is a tradition of the Indians that at one time the Turtle Bogue river emptied into the sea at what is now known as Cuatro Esquinas. At Colorado bar we doubtless have, as I have previously stated, the former channels of the Colorado river, now known as Simon and Agua Dulce lagoons, both pointing northward, besides this, further inland we have an abrupt turn to the northward by both the Colorado and the San Juan rivers. This change in direction may or may not have been produced by the same cause, but there is nothing in the topography of the country to make it improbable. This northward movement of the sand in my opinion is entirely

due to the northward shore current or eddy from the southward ocean current, the sand being kept more or less in suspension by the waves and breakers.

North of the Indian river the conditions to some extent are reversed and appear to contradict the foregoing. In going northward the sand upon the shore diminishes very perceptibly but seems to extend further into the sea than it does further south. North of Spanish creek the beach is very low, flat and compact, the sand is very much lighter in color and finer in grain than that near Greytown, but evidently of the same material, the darker and larger particles having been separated from it and lodged elsewhere. This sand from my own observations, extends as far north as Point of Rocks, and I am told that the same sand is to be found along the coast above Gorda point but in a still less quantity. This proves that the sand continues to move northward as far, at least, as the last named place, but between Point of Rocks and Corn river the shells upon the shore seem to indicate a southward drift.

On going northward from a few shells, mostly fragments, they increased in number and perfection until I came to a bed of live shells; immediately above this bed of live shells there was to be seen nothing but a few fragments of shells. The coral seemed to bear the same evidence. At Round Hill there is a coral formation, and the only place that I found any fragments of this substance is between Round Hill and a point about one mile south of Indian river. The evidence of the rivers is as follows: At their mouths; Indian river, a northward movement of sand; Spanish creek, a southward movement; Corn river, both directions, but the more recent is southward; Smart creek, southward. Further inland, it may be seen by the map that Indian river and Spanish creek indicate decidedly a southward drift of sand by the long tongues of land pointing southward that separate them from the sea. Spanish creek at one time had a much longer tongue intervening between it and the sea, for the evidences are that it at one time had the Haulover lagoon for its channel and Haulover for its entrance into the sea; Corn river beyond its mouth has not been influenced by the shifting sand in the sea; Smart creek being a small stream hugging the foot of the hills as far as I could see it, I did not investigate it further than the immediate vicinity of its mouth. These conflicting evidences of the direction in which the sand is drifted may be accounted for as follows: By referring to the map it will be seen that the coast line between Harbor Head and Gorda point forms quite a bay, and the northward shore current would naturally have a tendency to take a direct course between the last named points, leaving the water near the shore more or less dead. This current would take with it such sand as may be held in suspension until the waves produced by the prevailing northeast winds would drive it to the shore. These waves facing, say, S. 45° W. striking the shore whose direction is from south to S. 30° E. would make an angle of from 15° to 45° with the shore, diverging to the southward, thus tending to wash the sand along the coast in that direction. This action of the waves upon the sand is very perceptible in the vicinity of Greytown where the direction of the coast is east and west; the divergence of the angle that it makes with the waves is to the northward and westward and the movement of the sand is in the same directions. Further south, where the direction of the coast is practically the same as that between Greytown and Point of Rocks, it might be expected that the same result would occur, but south of

Harbor Head the northward shore current is close to the shore and is probably the stronger of the two forces acting upon the sand and directs their resultant to the northward. That there is a conflict between these two forces south of Harbor Head seems to be manifest from the irregular and chopped up condition of the shore that is not found northward from that point.

APPENDIX XI

REPORT OF L. HANKINS

Assistant Engineer

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APPENDIX XI

WASHINGTON, D. C., May 5, 1899.

MR. E. S. WHEELER,

Chief Engineer, Nicaragua Canal Commission, Washington, D. C.

Sir:—As requested in your letter of February 28, 1899, I have the honor to submit the following report of my operations while engaged with the Nicaragua Canal Commission of 1897-1899.

I was engaged as an engineer on April 18, 1898, and was directed to report to you at once at Greytown, Nicaragua. I proceeded to New York and took passage on the steamer "Alene," leaving April 23, 1898, with Messrs. Hughes, Collins, John Stockton, Durham and A. S. Miller. After a pleasant trip of fourteen days, stopping at Kingston, Jamaica, and Savanilla, Colombia, I arrived in Greytown May 5, 1898, and reported to you for duty.

I was assigned to duty with Mr. H. H. Trundle, who was then located near Ochoa. I remained in Greytown two days getting necessary camp outfit. I then proceeded up the San Juan river with Dr. C. W. Hayes and Mr. A. P. Davis in a twenty-foot canoe loaded with provisions, with three men to paddle. We were four days making the trip from Greytown to Ochoa. On account of the low water in the San Juan river it was necessary to get out of the boat repeatedly and push it over sand bars, which necessarily made the trip a slow one.

The first night, we camped in Mr. Onderdonk's old camp about eight miles from Greytown, where we were greeted with the usual rain storm and a full quota of mosquitoes. The second night, we camped in a native ranch on Paraiso island. The third day, we stopped at the Sarapiqui river, where I assisted Mr. Davis in gaging the river while the boatmen dried our bedding and Dr. Hayes made a sail of cheesecloth, with which we proceeded more rapidly up the San Juan and camped the third night at Maineri's. The fourth day, we reached Ochoa.

The preliminary survey for a low-level canal was then started from Ochoa to Greytown, Mr. Trundle, chief of party. I ran the transit and took topography from the Danta Divide to a point just east of the San Francisco hills, a distance of ten miles, and developed the topography for a distance of two to three thousand feet on each side of the center line. At the east side of the San Francisco hills we joined the line run by Mr. Boyd Ehle.

On August 5, 1898, we moved camp down the San Juan river three miles below the mouth of the Sarapiqui, and ran the preliminary line from the east slope of the Sarapiqui ridge down the Rio Negro valley a distance of six and one half miles, developing the topography about one thousand feet on each side of the line. This line joined the line run by Mr. Evans' party.

We then moved camp just below the Boca Colorado and developed some topography in the

Silico hills along the Pacific and Caribbean railroad.

On August 25, 1898, we moved camp to Greytown. From this date to September 15, the party were engaged in making maps and profiles of lines run.

Although it rained nearly every day while we were on the survey, the party did not lose a single day off the line and only twice were we compelled to stop work on account of rain preventing seeing through the instruments. I used one transit all the time, and although it was wet every day, it kept in perfect adjustment.

While making the survey and taking the topography, I naturally took note of the character of material along the line. Through the ridges the soil was of a clayey character and of such consistency as would require a slope of one to one. Through the swamps I should say from two to six feet deep was mud and decayed vegetable matter, below this a compact mass of fine silt, which will probably require a slope of two to one, although we noticed the banks of the watercourses through this material were nearly vertical from ten to fifteen feet high. Very little rock showed on the surface at any point, in fact at no place except along the ridge just east of San Francisco river, and here only in boulders of a volcanic character in the streams.

The material was such that if it were in the States it would not be classified at a higher price per cubic yard than is applied to the usual run of material consisting of rock, soft rock, clay, sand and silt, which prices usually run eighty, forty, twenty-five and twenty cents per cubic yard. To these prices a per cent. should be added on account of climatic conditions in Nicaragua, the principal of which is the excessive rainfall on the east side, an average of twenty-one feet a year. The distance from base of supplies will also have to be considered. I should think sixty-five per cent. would be a large estimate to add to the cost of each of these materials except where hard rock is encountered below the swamp level and in lock excavation.

On September 16, I sailed from Greytown on the steamer "Altai" in company with yourself and several others of the Commission, for New York, arriving there September 28, and left immediately for Washington where offices were engaged and work commenced on estimates for the canal.

On October 11, I was put in charge of one of the rooms as assistant engineer and have been engaged ever since projecting locations and working up estimates for a low-level canal line from the Caribbean sea to a point twenty-two and three-tenths miles west, where Mr. Trundle's work begins.

I have made locations for five different routes and worked up estimates of quantities for six-seven- and eight-lock systems on each line.

The lines are noted as follows: Line north of Lake Silico, Lull's Variant I, line through Lake Silico, Lull's Variant II, line south of Lake Silico from Greytown, Lull's Variant III, line south of Lake Silico from Harbor Head, Lull's Variant V, line from sea at Agua Dulce lagoon along the lower San Juan river, Lull's Variant IV.

These projected lines and estimates were made from a careful study of all preliminary surveys that were made in this territory by this Commission and all data from other sources.

I recommend Variant I, the line north of Lake Silico, which is located as follows: Commencing at the seven-fathom curve in the Caribbean sea northwest of the Greytown lighthouse, crossing Greytown lagoon in its deepest water and entering the mainland three thousand

feet south of La Fé or seven hundred feet south of the Maritime Canal Company's route, running thence south 49° 30′ west through the coastal plain, crossing the Rio San Juanillo and the Rio Misterioso, passing about two miles north of Lake Silico, crossing the first spur of ridges from the Silico hills five and one-half miles from the sea where the first lock is located, then along the Rio Misterioso valley the same course for a distance of one and one-quarter miles, then a 0° 30′ curve to the left for one and one-quarter miles, then south 18° 26′ west for a distance of five and two-tenths miles, crossing the main ridge from the Silico hills nine and one-quarter miles from the sea, where the second lock is located, then again along the Rio Misterioso valley crossing the Rio Pescado near its mouth, then along the south bank of the Rio San Juanillo, crossing this river the second and last time at a distance of fourteen and two-tenths miles from the sea. Here the line curves to the right on a 1° 0′ curve, four thousand one hundred and twenty-eight feet long, and enters the valley of the Rio Negro, then along the valley of the Rio Negro to the east slope of the Sarapiqui ridge where my line joins Mr. Trundle's line. The third lock is located in a ridge on the Rio Negro valley nineteen and seven-tenths miles from the sea. The length of this line north of Lake Silico from the seven-fathom curve to the east slope of the Sarapiqui ridge is twenty-two and three hundred and twenty-four thousandths miles. The approximate estimate for a six-lock system is as follows:

Dredging, sand and silt, 21,900,000 cubic yards at 37¢	$8,103,000
Canal section, dry excavation, 1,030,600 cubic yards at 37¢	381,322
Diversion, Rio San Juanillo, 476,000 cubic yards at 37¢	176,120
Canal section, dry excavation soft rock, 787,600 cubic yards at 93¢	732,468
Canal section, dry excavation hard rock, 281,900 cubic yards at 93¢	262,167
Greytown breakwater, stone, 550,000 cubic yards at $1.75	962,500
Rio Negro, waste-weir dry excavation, 410,000 cubic yards at 37¢	151,700
Rio Negro, waste-weir masonry, 2770 cubic yards at $8.30	22,991
Lock No. 1, waste-weir dry excavation, 26,000 cubic yards at 37¢	9,620
Lock No. 1, waste-weir masonry, 250 cubic yards at $8.30	2,075
Two locks, 18.4 lifts at $1,577,000	3,154,000
One lock, 18.4 lifts at $1,675,400	1,675,400
Stone pitching on embankments, 120,000 square yards at $2	240,000
Clearing 1500 acres at $75	112,500
Piers at Greytown Harbor, 5500 lin. feet at $150	825,000
Grubbing 750 acres at $100	75,000
Total	$16,885,863
Sheet piling at stream crossings 1,440,000 B. M.	86,400
Puddle embankments, 890,000 cubic yards at $1	890,000
Total	$17,862,263

The last two items, sheet piling and puddling, have been added at the suggestion of Colonel Peter C. Hains, where the head of the water in the canal is over twelve feet against embankments.

The material from the canal excavation is disposed of by depositing along the canal in embankments; and where the canal is in embankments the canal excavations will make a bank eight feet above the surface of the water and not less than fifty feet wide, and generally a much greater width than this. The embankments are also estimated to be from eight to twelve feet higher than the highest high water in the San Juan river.

As a practical question, I think building a canal through this section, amounts to nothing more than handling this volume of material under the conditions noted above, which can be overcome by adding a per cent. to the cost of similar work in the States.

Besides the five projected locations and estimates mentioned above, I have also made estimates of quantities on the line north of Lake Silico for a five-lock system, and on the same line for a six-lock system, width on bottom one hundred feet.

I also made estimates of quantities on the river section from Boca San Carlos to Purgatorio rapids, distance seventeen miles, for a low-level canal six-lock system of three dams in river, and worked this section the second time, lowering the grade five feet.

I have also projected a railroad location along the proposed low-level canal line from the Caribbean sea to Toro rapids, distance seventy-eight miles, and from Lake Nicaragua to the Pacific ocean at Brito, a distance of seventeen and one-half miles, and made profiles and estimates of quantities and cost of the projected railroad. The railroad is located directly along the canal route from two hundred to one thousand feet from the center line. There is nothing impracticable in connection with it, and it amounts to nothing more than simple railroad construction.

I have had to assist me in this work one draughtsman and two computers.

All the maps, profiles, cross sections and note books showing the lines I have projected and made estimates on, are filed with the Commission.

Very respectfully,

L. Hankins,
Assistant Engineer.

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